

**APPENDIX H**

**STATISTICAL AND GEOCHEMICAL EVALUATIONS  
OF SITE METALS DATA**

## **STATISTICAL EVALUATION**

# **Statistical Comparison of Site and Background Data For Impact Area South of POW, Parcels 100(Q) and 101(Q), Fort McClellan**

## **1.0 Introduction**

This report provides the Tier 1 and Tier 2 site-to-background comparison results for the Impact Area South of POW, Parcel 100(Q) and 101(Q), (IASPOW), Fort McClellan, in Calhoun County, Alabama. Tier 1 and Tier 2 evaluations (Shaw E & I, 2003) have been performed on the surface soil, total soil (surface soil and subsurface soil combined), and groundwater data sets. In the first step of the comparison, the maximum detected concentration (MDC) of each element is compared to two times the arithmetic mean of the background data (SAIC, 1998). Any metal that has an MDC greater than the background screening value is carried forward for Tier 2 evaluation, which includes the Slippage Test, the Wilcoxon Rank Sum Test (WRS), and Hot Measurement Test.

The methodology and results of the Tier 1 and Tier 2 comparisons are summarized in Tables 1 through 3, and described in more detail in the following sections. Site samples used in the site-to-background comparison include 22 surface soil samples (0 to 1 foot below ground surface [bgs]), 42 total soil samples (0 to 6 feet bgs), and 2 groundwater samples, that were collected at the site.

Background distributions and screening values have been established for target analyte list metals in surface soil (0 to 1 foot bgs), combine surface and subsurface soil (0 to 12 feet bgs), and groundwater for Fort McClellan (SAIC, 1998).

## **2.0 Comparison Methodology**

This section describes the statistical techniques that were employed in the IASPOW site-to-background comparisons.

### **2.1 Statistical Procedures**

Contamination can be caused by a variety of processes that yield different spatial distributions of elevated contaminant concentrations. Slight but pervasive contamination can occur from non-point-source releases, and can result in slight increases in contaminant concentrations in a large percentage of samples. Localized, or “hot-spot,” contamination can result in elevated

Table 1

**Summary of Tier 1 and Tier 2 Site to Background Comparison  
Surface Soil, Impact Area South of POW, Parcels 100(Q) and 101(Q)  
Fort McClellan  
Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation <sup>a</sup>	Slippage Test <sup>b</sup>	Wilcoxon Rank Sum Test <sup>b</sup>	Hot Measurement Test <sup>b,c</sup>	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	22 / 22	Failed	Passed	Failed	NA	Yes
Antimony	1 / 22	Failed	NA <sup>d</sup>	NA <sup>e</sup>	Passed	
Arsenic	22 / 22	Failed	Passed	Failed	NA	Yes
Barium	22 / 22	Failed	Passed	Failed	NA	Yes
Beryllium	22 / 22	Failed	Failed	Failed	NA	Yes
Cadmium	0 / 22	Passed	NA	NA	NA	
Calcium	22 / 22	Passed	NA	NA	NA	
Chromium	22 / 22	Failed	Passed	Failed	NA	Yes
Cobalt	22 / 22	Failed	Passed	Failed	NA	Yes
Copper	22 / 22	Failed	Failed	Failed	NA	Yes
Iron	22 / 22	Failed	Passed	Failed	NA	Yes
Lead	22 / 22	Failed	Failed	Failed	NA	Yes
Magnesium	22 / 22	Failed	Passed	Failed	NA	Yes
Manganese	22 / 22	Failed	Passed	Failed	NA	Yes
Mercury	16 / 22	Failed	Passed	NA <sup>e</sup>	Passed	
Nickel	22 / 22	Failed	Passed	Failed	NA	Yes
Potassium	22 / 22	Failed	Passed	Failed	NA	Yes
Selenium	4 / 22	Failed	Passed	NA <sup>e</sup>	Failed	Yes
Silver	4 / 22	Failed	Passed	NA <sup>e</sup>	Failed	Yes
Sodium	11 / 22	Passed	NA	NA	NA	
Thallium	0 / 22	Passed	NA	NA	NA	
Vanadium	22 / 22	Passed	NA	NA	NA	
Zinc	22 / 22	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

a Tier 1 evaluation (site MDC compared to 2 x the background mean) per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

d Slippage test is not performed on data sets for which the maximum background value is a nondetect.

e WRS test is not performed on data sets containing 50% or more nondetects.

Table 2

**Summary of Tier 1 and Tier 2 Site to Background Comparison  
Total Soil, Impact Area South of POW, Parcels 100(Q) and 101(Q)  
Fort McClellan  
Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation <sup>a</sup>	Slippage Test <sup>b</sup>	Wilcoxon Rank Sum Test <sup>b</sup>	Hot Measurement Test <sup>b,c</sup>	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	42 / 42	Failed	Passed	Failed	NA	Yes
Antimony	3 / 42	Failed	NA <sup>d</sup>	NA <sup>e</sup>	Failed	Yes
Arsenic	42 / 42	Failed	Passed	Failed	NA	Yes
Barium	42 / 42	Passed	NA	NA	NA	
Beryllium	36 / 42	Failed	Passed	Failed	NA	Yes
Cadmium	0 / 42	Passed	NA	NA	NA	
Calcium	40 / 42	Failed	Passed	Passed	NA	
Chromium	42 / 42	Failed	Passed	Failed	NA	Yes
Cobalt	38 / 42	Failed	Passed	Failed	NA	Yes
Copper	42 / 42	Failed	Failed	Failed	NA	Yes
Iron	42 / 42	Failed	Passed	Failed	NA	Yes
Lead	42 / 42	Failed	Passed	Failed	NA	Yes
Magnesium	42 / 42	Failed	Passed	Failed	NA	Yes
Manganese	42 / 42	Failed	Passed	Failed	NA	Yes
Mercury	31 / 42	Failed	Passed	NA <sup>e</sup>	Failed	Yes
Nickel	42 / 42	Failed	Passed	Failed	NA	Yes
Potassium	42 / 42	Failed	Passed	Failed	NA	Yes
Selenium	11 / 42	Failed	Failed	NA <sup>e</sup>	Failed	Yes
Silver	6 / 42	Failed	Failed	NA <sup>e</sup>	Failed	Yes
Sodium	20 / 42	Passed	NA	NA	NA	
Thallium	0 / 42	Passed	NA	NA	NA	
Vanadium	42 / 42	Passed	NA	NA	NA	
Zinc	42 / 42	Failed	Passed	Failed	NA	Yes

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

a Tier 1 evaluation (site MDC compared to 2 x the background mean) per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

d Slippage test is not performed on data sets for which the maximum background value is a nondetect.

e WRS test is not performed on data sets containing 50% or more nondetects.

Table 3

**Summary of Tier 1 and Tier 2 Site to Background Comparison  
Groundwater, Impact Area South of POW, Parcels 100(Q) and 101(Q)  
Fort McClellan  
Calhoun County, Alabama**

Metals	Frequency of Detection	Tier 1 Evaluation <sup>a</sup>	Slippage Test <sup>b</sup>	Wilcoxon Rank Sum Test <sup>b</sup>	Hot Measurement Test <sup>b,c</sup>	Carried Forward for Tier 3 Geochemical Evaluation
Aluminum	2 / 2	Passed	NA	NA	NA	
Antimony	0 / 2	NA	NA	NA	NA	
Arsenic	0 / 2	NA	NA	NA	NA	
Barium	1 / 2	Passed	NA	NA	NA	
Beryllium	0 / 2	NA	NA	NA	NA	
Cadmium	0 / 2	NA	NA	NA	NA	
Calcium	0 / 2	NA	NA	NA	NA	
Chromium	0 / 2	NA	NA	NA	NA	
Cobalt	1 / 2	Passed	NA	NA	NA	
Copper	0 / 2	NA	NA	NA	NA	
Iron	2 / 2	Passed	NA	NA	NA	
Lead	0 / 2	NA	NA	NA	NA	
Magnesium	0 / 2	NA	NA	NA	NA	
Manganese	2 / 2	Failed	Passed	NA <sup>d</sup>	Passed	
Mercury	0 / 2	NA	NA	NA	NA	
Nickel	0 / 2	NA	NA	NA	NA	
Potassium	0 / 2	NA	NA	NA	NA	
Selenium	0 / 2	NA	NA	NA	NA	
Silver	0 / 2	NA	NA	NA	NA	
Sodium	0 / 2	NA	NA	NA	NA	
Thallium	0 / 2	NA	NA	NA	NA	
Vanadium	0 / 2	NA	NA	NA	NA	
Zinc	0 / 2	NA	NA	NA	NA	

NA = not applicable; MDC = maximum detected concentration; UTL = upper tolerance limit

a Tier 1 evaluation (site MDC compared to 2 x the background mean) per **Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2**, Technical Memorandum, 24 June 2003 by Paul Goetchius.

b Part of Tier 2 evaluation per the above referenced memo.

c Performed only when the Slippage test and/or WRS test cannot be performed.

d WRS test is not performed on data sets with less than 5 samples.

concentrations in a small percentage of the total number of site samples. No single two-sample statistical comparison test is sensitive to both of these modes of contamination. For this reason, the use of several simultaneous tests is recommended for a valid and complete comparison of site versus background distributions (U.S. Environmental Protection Agency [EPA], 1989, 1992, and 1994; U.S. Navy, 2002).

Analytes that fail the Tier 1 and Tier 2 comparisons are subject to a geochemical evaluation to determine if the elevated concentrations are due to natural processes or if they represent potential contamination.

**2.1.1 Tier 1 -** In this step of the background screening process, the maximum detected concentration (MDC) of the site data set is compared to the background screening value of two times the background mean (SAIC, 1998). Elements for which the site MDC does not exceed the background screening value are considered to be present at background concentrations, and are not considered site-related chemicals. Elements for which the site MDC exceeds the background screening value undergo further evaluation (Tier 2).

#### **2.1.2 Tier 2 –**

**Slippage Test –** The nonparametric Slippage test is designed to detect a difference between the upper tails of two distributions, and has been recommended for use in site-to-background comparisons to identify potential localized, or hot-spot, contamination (U.S. Navy, 2002). The test is performed by counting the number ( $K$ ) of detected concentrations in the site data set that exceed the maximum background measurement, and then comparing this number to a critical value ( $K_c$ ), which is a function of the number of background samples and the number of site samples. If  $K > K_c$ , then potential contamination is indicated and the analyte will be subjected to geochemical evaluation. If  $K \leq K_c$ , then localized contamination is not suspected.

Critical values tables for site and background data sets up to size  $n = 50$  are provided in U.S. Navy (2002). Critical values for larger data sets are calculated using the test statistic provided in Rosenbaum (1954). In this report, the Slippage test is performed at the 95 percent confidence level. The test cannot be performed if the maximum background value is a nondetect, because the actual concentration in that sample is unknown.

**Wilcoxon Rank Sum Test.** The nonparametric WRS test is designed to detect a difference between the medians of two data sets, and has been recommended for use in site-to-background comparisons to identify slight but pervasive contamination (EPA, 2000; U.S. Navy, 2002). In

this report, the WRS test is performed when the site and background data sets each contain less than 50 percent nondetects (i.e., measurements reported as not detected below the laboratory reporting limit). The WRS test will not be performed on data sets containing 50 percent or more nondetects. The medians of such data sets are unknown, and hence the test results would lack sufficient power to yield reliable results.

The WRS test compares two data sets of size  $n$  and  $m$  ( $n > m$ ), and tests the null hypothesis that the samples were drawn from populations with distributions having the same medians. To perform the test, the two sets of observations are pooled and arranged in order from smallest to largest. Each observation is assigned a rank; that is, the smallest is ranked 1, the next largest is ranked 2, and so on up to the largest observation, which is ranked  $(n + m)$ . If ties occur between or within samples, each one is assigned the mid-rank. Next, the sum of the ranks of smaller data set  $m$  is calculated. Then the test statistic  $Z$  is determined,

$$Z = \frac{W - m(m + n + 1)/2}{\sqrt{mn(m + n + 1)/12}}$$

Where:

- $W$  = Sum of the ranks of the smaller data set
- $m$  = Number of data points in smaller group
- $n$  = Number of data points in larger group.

This test statistic  $Z$  is used to find the two-sided significance. For instance, if the test statistic yields a probability of a Type I error (p-level) less than 0.2, then there is a statistically significant difference between the medians at the 80 percent confidence level. A Type I error involves rejecting the null hypothesis when it is true. If the p-level is greater than 0.2, then there is no reasonable justification to reject the null hypothesis at the 80 percent confidence level. It can therefore be concluded that the medians of the two data sets are similar, and it can be assumed to be drawn from the same population.

If the p-level is less than 0.2, then the medians of the two distributions are significantly different at the 80 percent confidence level. This can occur if the site data are shifted higher or lower than the background data. If the site data are shifted higher relative to background, then contamination may be indicated, and the analyte in question will be carried on for geochemical evaluation; however, if the site data are shifted lower relative to background, then contamination



is not indicated. If the p-level is greater than 0.2, then pervasive site contamination is not suspected.

**Box Plots.** A quick, robust graphical method recommended by the EPA to visualize and compare two or more groups of data is the box plot comparison (EPA, 1989 and 1992). These plots provide a summary view of the entire data set, including the overall location and degree of symmetry. The box encloses the central 50 percent of the data points so that the top of the box represents the 75<sup>th</sup> percentile and the bottom of the box represents the 25<sup>th</sup> percentile. The small box within the larger box represents the median of the data set. The upper whisker extends outward from the box to the maximum point and the lower whisker extends to the minimum point. Nondetect results are set equal to one-half of the reporting limit for plotting purposes.

For each analyte, box plots of site and background data are placed side by side to visually compare the distributions and qualitatively determine whether the data sets are similar or distinct. Accordingly, the box plots are a necessary adjunct to the WRS test. As described previously, the WRS test may indicate that the medians of the site and background data sets are significantly different. Examination of the box plots will confirm whether that difference is caused by site data that are shifted higher or lower relative to background.

**Hot Measurement Test.** The hot measurement test consists of comparing each site measurement with a concentration value that is representative of the upper limit of the background distribution (EPA, 1994). Ideally, a site sample with a concentration above the background screening value would have a low probability of being a member of the background distribution, and may be an indicator of contamination. It is important to select such a background screening value carefully so that the probability of falsely identifying site samples as contaminated or uncontaminated is minimized.

The 95<sup>th</sup> upper tolerance limit (95<sup>th</sup> UTL) is recommended as a screening value for normally or lognormally distributed analytes and the 95<sup>th</sup> percentile is recommended as a screening value for nonparametrically distributed analytes (EPA, 1989, 1992, and 1994). Site samples with concentrations above these values are not necessarily contaminated, but should be considered suspect. To perform the test, each analyte's site MDC is compared to the background 95<sup>th</sup> UTL or 95<sup>th</sup> percentile, in accordance with the type of background distribution. If the site MDC exceeds the background screening value, then that analyte will undergo a geochemical evaluation. If the MDC does not exceed the background threshold value, then hot-spot contamination is not indicated.

### **2.1.3 Geochemical Evaluation**

If an analyte fails either of the statistical tests described above then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The methodology and results of the geochemical evaluation are provided in Appendix H.

## **3.0 Results of the Site-to-Background Comparisons**

This section presents the results of the site-to-background comparisons for 23 TAL metals in the IASPOW surface soil, total soil, and groundwater samples. The WRS test results with corresponding box plots are provided in Attachment 1. Tables 1 through 3 summarize the Tier 1 and Tier 2 test results for each media as discussed in the following sections.

### **3.1 Surface Soil**

Twenty-three TAL metals were evaluated in the IASPOW surface soil. Two metals, cadmium and thallium, had no detected concentrations in surface soil, so no further discussion of these metals is included. Calcium, sodium and vanadium passed the Tier 1 evaluation having no detected concentrations exceeding the background screening value. These metals will not be considered or discussed further. The remaining eighteen metals are carried forward for Tier 2 evaluation.

Table 1 summarizes the surface soil statistical site to background comparison results. Box plots are provided in Attachment 1.

#### **Aluminum**

##### Tier 1 Evaluation

Twenty site samples exceed the background screening value of 16,306 mg/kg.

##### Slippage Test

The critical value,  $K_c$ , for aluminum is 3, and no site samples exceed the maximum background measurement ( $K = 0$ ). Because  $K < K_c$ , aluminum passes the Slippage test.

##### WRS Test

The p-level of  $< 0.001$  indicates significant difference between the site and background distributions.

##### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-1).

### Conclusion

Because aluminum in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Antimony**

#### Tier 1 Evaluation

One site sample exceeds the background screening value of 1.99 mg/kg.

#### Slippage Test

Because the maximum result of antimony in background is a nondetect, this test could not be performed.

#### WRS Test

The site data set contained greater than 50 percent nondetects (95 percent), so this test could not be performed.

#### Hot Measurement Test

The MDC of antimony is less than the background 95<sup>th</sup> percentile of 7.14 mg/kg.

#### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-1). The shape and location of the site box plot reflects the high percentage of nondetects (95 percent), and the replacement values of one-half the reporting limit rather than detected concentrations.

### Conclusion

Antimony is considered within the range of background based on the Hot Measurement test.

### **Arsenic**

#### Tier 1 Evaluation

Two site samples of arsenic exceed the background screening value of 13.73 mg/kg.

#### Slippage Test

The critical value,  $K_c$ , for arsenic is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , arsenic passes the Slippage test.

#### WRS Test

The p-level of  $< 0.001$  indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-2).

### Conclusion

Because arsenic in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Barium**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 123.94 mg/kg.

### Slippage Test

The  $K_c$  for barium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , barium passes the Slippage test.

### WRS Test

The p-level of 0.002 indicates significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-2).

### Conclusion

Because barium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Beryllium**

### Tier 1 Evaluation

Eight site samples exceed the background screening value of 0.8 mg/kg.

### Slippage Test

$K_c$  is 3 and seven site samples exceed the maximum background measurement. Because  $K > K_c$ , beryllium fails the Slippage test.

### WRS Test

The p-level of  $< 0.001$  indicates significant difference between the site and background distributions.

### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-3).

### Conclusion

Because beryllium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Chromium**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 37.04 mg/kg.

### Slippage Test

$K_c$  for chromium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , chromium passes the Slippage test.

### WRS Test

The p-level of 0.02 indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the respective background values (Figure 1-3).

### Conclusion

Because chromium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Cobalt**

### Tier 1 Evaluation

One site sample exceeds the background screening value of 15.15 mg/kg.

### Slippage Test

$K_c$  for cobalt is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , cobalt passes the Slippage test.

### WRS Test

The p-level of  $< 0.001$  indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the respective background values (Figure 1-4).

### Conclusion

Because cobalt in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Copper**

### Tier 1 Evaluation

Nineteen site samples exceed the background screening value of 12.71 mg/kg.

#### Slippage Test

$K_c$  for copper is 3, and fourteen site samples exceed the maximum background measurement. Because  $K > K_c$ , copper fails the Slippage test.

#### WRS Test

The p-level of  $< 0.001$  indicates a significant difference between the site and background distributions.

#### Box Plot

The site minimum, interquartile range, and maximum are higher than the respective background values (Figure 1-4).

#### Conclusion

Because copper in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Iron**

#### Tier 1 Evaluation

Two site samples exceed the background screening value of 34,154 mg/kg.

#### Slippage Test

The critical value,  $K_c$ , for iron is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$  iron passes the Slippage test.

#### WRS Test

The p-level of  $< 0.001$  indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are visibly higher with respect to the corresponding background values (Figure 1-5).

#### Conclusion

Because iron in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Lead**

#### Tier 1 Evaluation

Eighteen detected concentrations of lead in site samples exceed the background screening value of 40.05 mg/kg.

#### Slippage Test

$K_c$  for lead is 3, and thirteen site samples exceed the maximum background measurement. Because  $K > K_c$ , lead fails the Slippage test.

#### WRS Test

The p-level < 0.001 indicates a significant difference between the site and background distributions.

#### Box Plot

The site minimum, interquartile range, and maximum are higher than that of background (Figure 1-5).

#### Conclusion

Because lead in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Magnesium**

#### Tier 1 Evaluation

Three site samples exceed the background screening value of 1,033 mg/kg.

#### Slippage Test

$K_c$  for magnesium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , magnesium passes the Slippage test.

#### WRS Test

The p-level < 0.001 indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are higher with respect to the corresponding background values (Figure 1-6).

#### Conclusion

Because magnesium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Manganese**

#### Tier 1 Evaluation

Twelve site samples exceed the background screening value of 1,579 mg/kg.

#### Slippage Test

The critical value,  $K_c$ , for manganese is three. No detects in site samples exceed the maximum background measurement. Because  $K < K_c$ , manganese passes the Slippage test.

#### WRS Test

The p-level < 0.001 indicates good agreement between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than their respective background values (Figure 1-6).

### Conclusion

Because manganese in surface soil failed statistical comparison to background, it is carried forward for Tier 3 geochemical evaluation.

## **Mercury**

### Tier 1 Evaluation

Two site samples exceed the background screening value of 0.08 mg/kg.

### Slippage Test

The critical value for mercury,  $K_c$ , is 3, and no site samples exceed the maximum background measurement. Since  $K < K_c$ , mercury passes the Slippage test.

### WRS Test

The WRS test was not performed because the background data set contains more than 50 percent nondetects.

### Box Plot

The site minimum and interquartile range are elevated relative to their corresponding background values (Figure 1-7). The shape and location of the background box plot reflects the high percentage of nondetects (66 percent), and the replacement values of one-half the reporting limit rather than detected concentrations.

### Hot Measurement Test

No site samples of mercury exceed the background 95<sup>th</sup> percentile of 0.125 mg/kg.

### Conclusion

Mercury in surface soil is considered within the range of background.

## **Nickel**

### Tier 1 Evaluation

Fifteen site samples exceed the background screening value of 10.33 mg/kg.

### Slippage Test

$K_c$  for nickel is three, and no site samples exceed maximum background measurement. Because  $K < K_c$  nickel passes the Slippage test.

### WRS Test

The p-level  $< 0.001$  indicates a significant difference between the site and background distributions.



#### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-7).

#### Conclusion

Because nickel in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Potassium**

#### Tier 1 Evaluation

Nine site samples exceed the background screening value of 799.76 mg/kg.

#### Slippage Test

$K_c$  for potassium is three, and no site samples exceed maximum background measurement. Because  $K < K_c$  potassium passes the Slippage test.

#### WRS Test

The p-level  $< 0.001$  indicates a significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-8).

#### Conclusion

Because potassium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Selenium**

#### Tier 1 Evaluation

Four detected concentrations in the site data set exceed the background screening value of 0.48 mg/kg.

#### Slippage Test

$K_c$  for selenium is 3, and two site samples exceed the maximum background measurement. Because  $K < K_c$ , selenium passes the Slippage test.

#### WRS Test

No WRS test was performed because the site and background data sets each contain greater than 50 percent nondetects.

#### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-8). The shapes and locations of the background and site box plots reflect the high percentage of nondetects (99% and 82% respectively), and the replacement values of one-half the reporting limit rather than detected concentrations.

#### Hot Measurement Test

The site MDC exceeds the background 95<sup>th</sup> percentile of 0.563 mg/kg.

#### Conclusion

Because selenium in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Silver**

#### Tier 1 Evaluation

Four site samples exceed the background screening value of 0.36 mg/kg.

#### Slippage Test

$K_c$  for silver is 3, and two site samples exceed the maximum background measurement. Because  $K < K_c$ , silver passes the Slippage test.

#### WRS Test

No WRS test was performed because the site data set contains greater than 50 percent nondetects.

#### Box Plot

The site minimum and interquartile range are much higher than the corresponding background values (Figure 1-9). The shape and location of the site box plot reflects the high percentage of nondetects (82% respectively), and the replacement values of one-half the reporting limit rather than detected concentrations.

#### Hot Measurement Test

The site MDC exceeds the background 95<sup>th</sup> percentile of 0.774 mg/kg.

#### Conclusion

Because silver in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Zinc**

#### Tier 1 Evaluation

Seven site samples exceed the background screening value of 40.64 mg/kg.

#### Slippage Test

$K_c$  for zinc is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , zinc passes the Slippage test.

#### WRS Test

The p-level  $< 0.001$  indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the respective background values (Figure 1-9).

### Conclusion

Because zinc in surface soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **3.2 Total Soil**

Twenty-three TAL metals were evaluated in the IASPOW total soil. Two metals, cadmium and thallium, had no detected concentrations in total soil so no further discussion of these metals is included. In addition, three metals, (barium, sodium, and vanadium) have MDCs less than their respective background screening values. Because these metals passed the Tier 1 evaluation, they will not be discussed further.

Table 2 summarizes the total soil statistical site to background comparison results. The remaining eighteen metals are carried forward for Tier 2 evaluation, and the test results are discussed below in detail. Box plots are provided in Attachment 1.

## **Aluminum**

### Tier 1 Evaluation

Thirty-nine site samples of aluminum exceed the background screening value of 15,009 mg/kg.

### Slippage Test

The critical value,  $K_c$ , of aluminum is 3. No site samples exceed the maximum background measurement ( $K = 0$ ). Because  $K < K_c$ , aluminum passes the Slippage test.

### WRS Test

The p-level  $< 0.001$  indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-10).

### Conclusion

Because aluminum in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Antimony**

### Tier 1 Evaluation

Three site samples exceed the background screening value of 1.655 mg/kg.

#### Slippage Test

Because the maximum result in background is a nondetect, the Slippage test is not performed.

#### WRS Test

The WRS test was not performed because the site data set contains more than 50 percent nondetects (93 percent).

#### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-10).

#### Hot Measurement Test

The site MDC exceeds the background 95<sup>th</sup> percentile of 7.14 mg/kg.

#### Conclusion

Because antimony in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Arsenic**

#### Tier 1 Evaluation

Two site samples exceed the background screening value of 15.975 mg/kg.

#### Slippage Test

$K_c$  for arsenic is 3, and one site sample exceeds the maximum background measurement. Because  $K < K_c$ , arsenic passes the Slippage test.

#### WRS Test

The p-level  $< 0.001$  indicates a significant difference in the site and background distributions.

#### Box Plot

The site minimum is much higher than that of background, and the interquartile range is just slightly elevated as compared to the respective background values (Figure 1-11).

#### Conclusion

Because arsenic in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Beryllium**

#### Tier 1 Evaluation

Eight site samples of beryllium exceed the background screening value of 0.831 mg/kg.

#### Slippage Test

$K_c$  for beryllium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , beryllium passes the Slippage test.

#### WRS Test

The p-level < 0.001 indicates a significant difference in the site and background distributions.

#### Box Plot

The site minimum and interquartile range are higher than the corresponding background values (Figure 1-11).

#### Conclusion

Because beryllium in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Calcium**

#### Tier 1 Evaluation

One site sample exceeds the background screening value of 1,204 mg/kg.

#### Slippage Test

$K_c$  for calcium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , calcium passes the Slippage test.

#### WRS Test

The p-level of 0.32 indicates good agreement between the site and background distributions.

#### Box Plot

The site minimum is slightly higher than that of background, but the medians are similar and the site 25<sup>th</sup> percentile, 75<sup>th</sup> percentile and maximum are lower than the corresponding background values (Figure 1-12).

#### Conclusion

Calcium in total soil is considered within the range of background.

### **Chromium**

#### Tier 1 Evaluation

Three site samples exceed the background screening value of 37.6 mg/kg.

#### Slippage Test

The critical value,  $K_c$ , for chromium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , chromium passes the Slippage test.

#### WRS Test

The p-level of 0.0238 indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum, 25<sup>th</sup> percentile and median are slightly elevated as compared to their respective background values (Figure 1-12).

### Conclusion

Because chromium in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Cobalt**

#### Tier 1 Evaluation

Two site samples exceed the background screening value of 16.3 mg/kg.

#### Slippage Test

The critical value,  $K_c$ , for cobalt is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , cobalt passes the Slippage test.

#### WRS Test

The p-level  $< 0.001$  indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are slightly elevated as compared to their respective background values (Figure 1-13).

### Conclusion

Because cobalt in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Copper**

#### Tier 1 Evaluation

Eighteen site samples exceed the background screening value of 15.93 mg/kg.

#### Slippage Test

$K_c$  for copper is 3, and five site samples exceed the maximum background measurement. Because  $K > K_c$ , copper fails the Slippage test.

#### WRS Test

The p-level of  $< 0.001$  indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum, interquartile range, and maximum are higher than the respective background values (Figure 1-13).

### Conclusion

Because copper in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Iron**

### Tier 1 Evaluation

Four site samples exceed the background screening value of 39,247 mg/kg.

### Slippage Test

$K_c$  for iron is 3, and no site sample exceeds the maximum background measurement. Because  $K < K_c$ , iron passes the Slippage test.

### WRS Test

The  $p$ -level  $< 0.001$  indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum and interquartile range are higher than the respective background values (Figure 1-14).

### Conclusion

Because iron in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Lead**

### Tier 1 Evaluation

Twenty-one site samples exceed the background screening value of 39.3 mg/kg.

### Slippage Test

$K_c$  for lead is 3, and three site samples exceed the maximum background measurement. Because  $K \leq K_c$ , lead passes the Slippage test.

### WRS Test

The  $p$ -level  $< 0.001$  indicates a significant difference between the site and background distributions.

### Box Plot

The site minimum, interquartile range, and maximum are higher than the respective background values (Figure 1-14).

### Conclusion

Because lead in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

## **Magnesium**

### Tier 1 Evaluation

Five site samples exceed the background screening value of 905.58 mg/kg.

#### Slippage Test

$K_c$  for magnesium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , magnesium passes the Slippage test.

#### WRS Test

The p-level  $< 0.001$  indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are visibly higher with respect to background (Figure 1-15).

#### Conclusion

Because magnesium in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Manganese**

#### Tier 1 Evaluation

Fifteen site samples exceed the background screening value of 1,472 mg/kg.

#### Slippage Test

$K_c$  for manganese is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , manganese passes the Slippage test.

#### WRS Test

The p-level  $< 0.001$  indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are visibly higher with respect to the corresponding background values (Figure 1-15).

#### Conclusion

Because manganese in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Mercury**

#### Tier 1 Evaluation

Fourteen site samples exceed the background screening value of 0.0704 mg/kg.

#### Slippage Test

The critical value for mercury,  $K_c$ , is 3, and no site samples exceed the maximum background measurement. Since  $K < K_c$ , mercury passes the Slippage test.



#### WRS Test

The WRS test was not performed because the background data set contains more than 50 percent nondetects.

#### Box Plot

The site minimum and interquartile range are elevated relative to the corresponding background values (Figure 1-16). The shape and location of the background box plot is influenced by the percentage of nondetects (60 percent), and the replacement values of one-half the reporting limit rather than detected concentrations.

#### Hot Measurement Test

The site MDC of mercury exceeds the background 95<sup>th</sup> percentile of 0.094 mg/kg.

#### Conclusion

Because mercury in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Nickel**

#### Tier 1 Evaluation

Eighteen site samples exceed the background screening value of 11.56 mg/kg.

#### Slippage Test

$K_c$  for nickel is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , nickel passes the Slippage test.

#### WRS Test

The p-level of  $< 0.001$  indicates a difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are higher than the respective background values (Figure 1-16).

#### Conclusion

Because nickel in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Potassium**

#### Tier 1 Evaluation

Fifteen site samples exceed the background screening value of 757.24 mg/kg.

#### Slippage Test

$K_c$  for potassium is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , potassium passes the Slippage test.

#### WRS Test

The  $p$ -level  $< 0.001$  indicates significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are visibly higher with respect to background (Figure 1-17).

#### Conclusion

Because potassium in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Selenium**

#### Tier 1 Evaluation

Eleven site samples exceed the background screening value of 0.48 mg/kg.

#### Slippage Test

$K_c$  for selenium is 3, and six site samples exceed the maximum background measurement. Because  $K > K_c$ , selenium fails the Slippage test.

#### WRS Test

No WRS test was performed because the background data set contains greater than 50 percent nondetects.

#### Box Plot

The site minimum, interquartile range, and maximum are higher than the corresponding background values (Figure 1-17). The shape and location of the background box plot reflects the high percentage of nondetects (98 percent), and the replacement values of one-half the reporting limit.

#### Hot Measurement Test

The site MDC exceeds the background 95<sup>th</sup> percentile of 0.571 mg/kg.

#### Conclusion

Because selenium in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Silver**

#### Tier 1 Evaluation

Six site samples exceed the background screening value of 0.303 mg/kg.

#### Slippage Test

$K_c$  for silver is 3, and four site samples exceed the maximum background measurement. Because  $K > K_c$ , silver fails the Slippage test.

#### WRS Test

No WRS test was performed because the site data set contains greater than 50 percent nondetects.

#### Box Plot

The site minimum and interquartile range are significantly higher than the corresponding background values (Figure 1-18). The site maximum is also higher than that of background.

#### Hot Measurement Test

The site MDC exceeds the background 95<sup>th</sup> percentile of 0.803 mg/kg.

#### Conclusion

Because silver in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **Zinc**

#### Tier 1 Evaluation

Thirteen site samples exceed the background screening value of 37.88 mg/kg.

#### Slippage Test

$K_c$  for zinc is 3, and no site samples exceed the maximum background measurement. Because  $K < K_c$ , zinc passes the Slippage test.

#### WRS Test

The p-level  $< 0.001$  indicates a significant difference between the site and background distributions.

#### Box Plot

The site minimum and interquartile range are visibly higher than the respective background values (Figure 1-18).

#### Conclusion

Because zinc in total soil failed statistical comparison to background, it will be carried forward for Tier 3 geochemical evaluation.

### **3.3 Groundwater**

This section presents the results of the site-to-background comparisons for 23 metals unfiltered groundwater samples. Eighteen metals (antimony, arsenic, beryllium, cadmium, calcium, chromium, copper, lead, magnesium, mercury, nickel, potassium, selenium, silver, sodium, thallium, vanadium, and zinc) had no detects in the groundwater site samples and are not considered any further. Four metals (aluminum, barium, cobalt, and iron) had no detected concentrations that exceeded their respective background screening values. These metals are considered within the background range based on the Tier 1 evaluation, and will not be tested or discussed further. Table 2 summarizes these results.

The remaining metal, manganese has an MDC that exceeds the background screening value, and is carried forward for Tier 2 evaluation. The results of this evaluation are summarized in Table 3 and discussed in detail below. Box plots are provided in Attachment 1.

## **Manganese**

### Tier 1 Evaluation

One sample exceeds the background screening value of 0.58 mg/L.

### Slippage Test

$K_c$  for manganese is 1, and no site sample exceeds the maximum background measurement. Because  $K < K_c$ , manganese passes the Slippage test.

### WRS Test

No WRS test was performed because the site data set has less than 5 samples.

### Box Plot

The site minimum and interquartile range are elevated as compared to the corresponding background values (Figure 1-19).

### Hot Measurement Test

The site MDC is less than the background 95<sup>th</sup> upper tolerance limit of 4.13 mg/L.

### Conclusion

Manganese in groundwater is considered within the range of background.

## **4.0 Summary and Conclusions**

The statistical methodology used to compare the Impact Area South of POW, Parcel 100(Q) and 101(Q), and background data sets for 23 elements in surface soil, total soil, and groundwater includes a comparison of the site MDC to the background screening value, Tier 1 evaluation. Analytes that failed this comparison were subjected to the Slippage test and WRS test. Box-and-whisker plots were prepared to visually compare the two data sets and properly interpret the WRS test results. For elements with data sets that did not allow for either the Slippage test or WRS test to be performed, the Hot Measurement test was used. Analytes that failed these statistical tests, Tier 2 evaluation, are carried forward for Tier 3 geochemical evaluation to determine if natural processes can explain the elevated concentrations.

Tables 1 through 3 summarize the comparison test results and show the metals carried forward for geochemical evaluation.

## 5.0 References

Rosenbaum, S., 1954, "Tables for a Nonparametric Test of Location," *Annals of Mathematical Statistics*, Vol. 24, pp. 146-150.

Science Application International Corporation (SAIC), 1998, *Final Background Metals Survey Report, Fort McClellan, Anniston, Alabama*, prepared for U.S. Army Corps of Engineers, Mobile, Alabama, July.

Shaw Environmental and Infrastructure (Shaw E&I), 2003, *Selecting Site-Related Chemicals for Human Health and Ecological Risk Assessments for FTMC, Revision 2*, Technical Memorandum, 24 June 2003 by Paul Goetchius.

U.S. Environmental Protection Agency (EPA), 1989, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Interim Final Guidance*, Office of Solid Waste, Waste Management Division, EPA/530/SW-89/026, July.

U.S. Environmental Protection Agency (EPA), 1992, *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance*, Environmental Statistics and Information Division, Office of Policy, Planning, and Evaluation, EPA/530/R-93/003, July.

U.S. Environmental Protection Agency (EPA), 1994, *Statistical Methods For Evaluating The Attainment Of Cleanup Standards*, Environmental Statistics and Information Division, Office of Policy, Planning, and Evaluation, EPA/230/R-94/004, June.

U.S. Environmental Protection Agency (EPA), 2000, *Guidance for Data Quality Assessment: Practical Methods for Data Analysis, EPA QA/G-9, QA00 Update*, Office of Environmental Information, EPA/600/R-96/084, July.

U.S. Navy, 2002, *Guidance for Environmental Background Analysis, Volume 1: Soil*, NFESC User's Guide UG-2049-ENV, Naval Facilities Engineering Command, Washington, D.C., April.

## **ATTACHMENT 1**

Figure 1-1

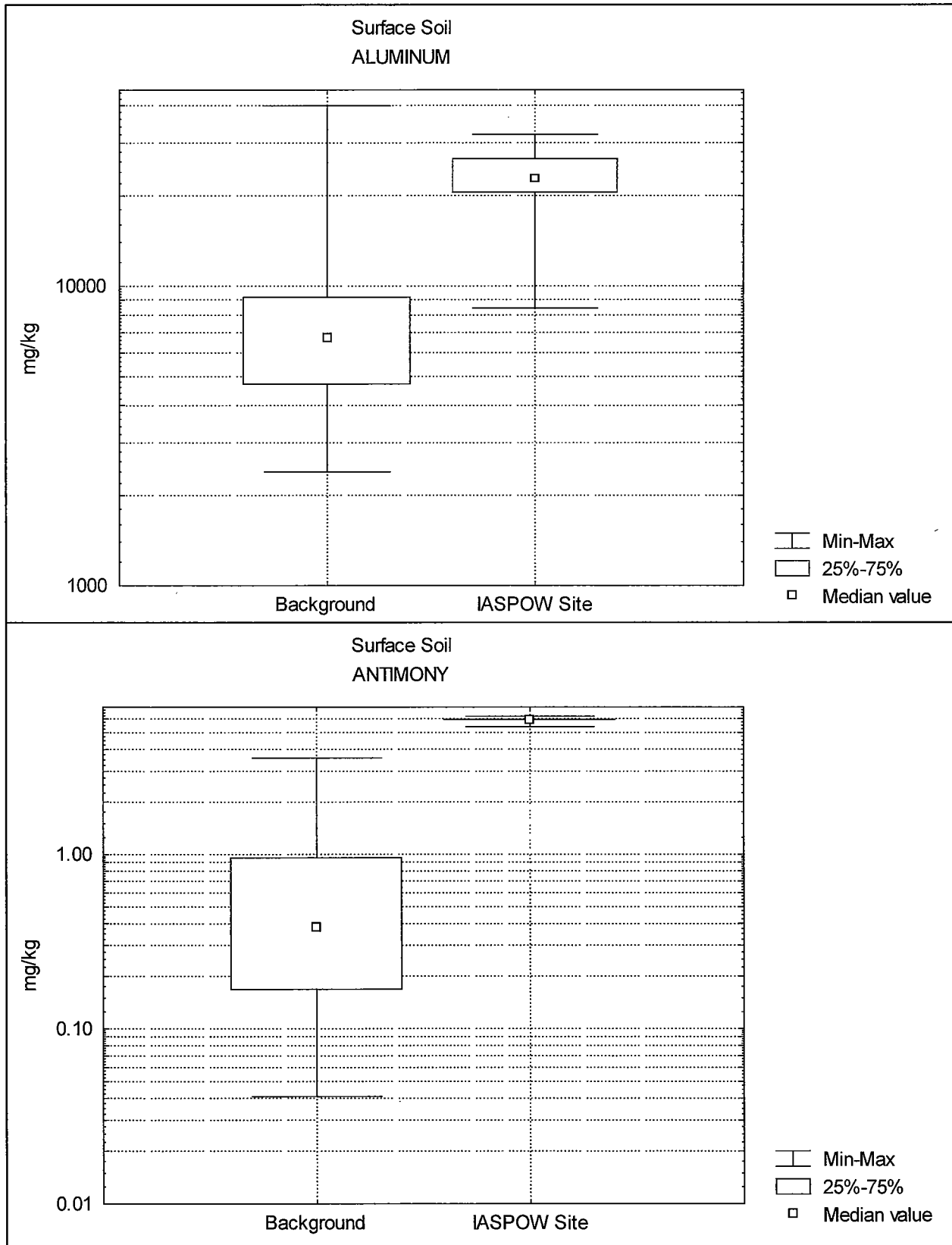


Figure 1-2

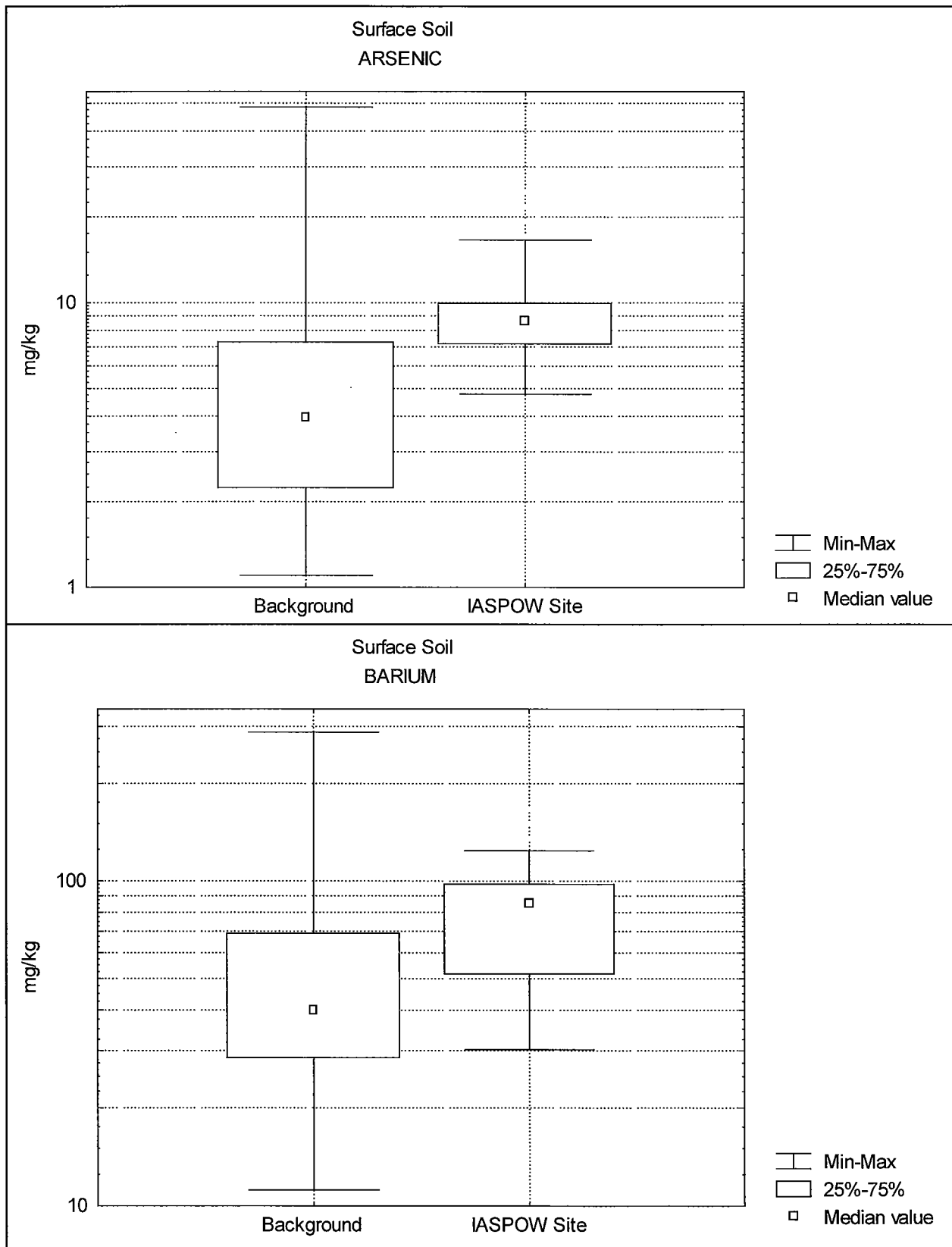




Figure 1-3

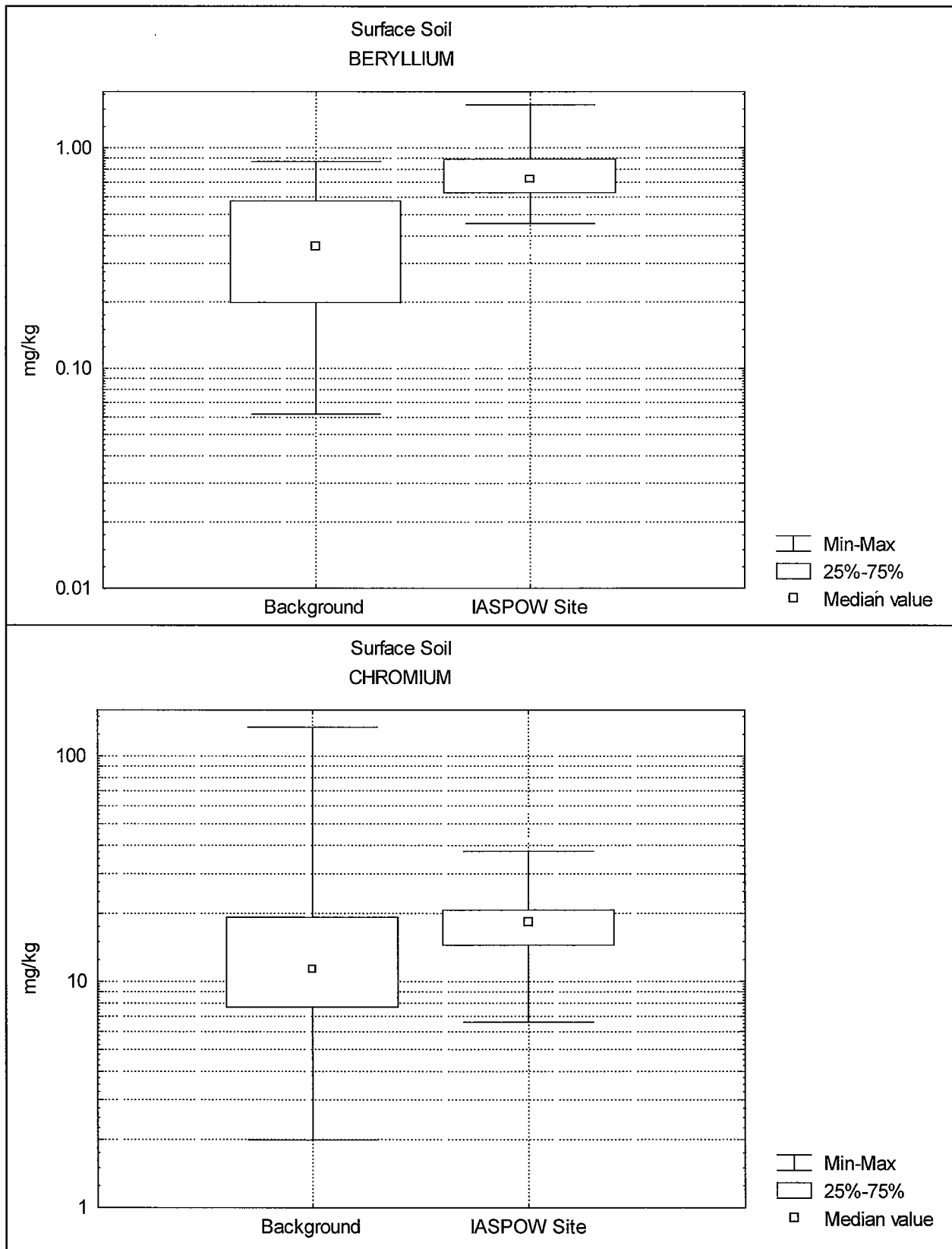


Figure 1-4

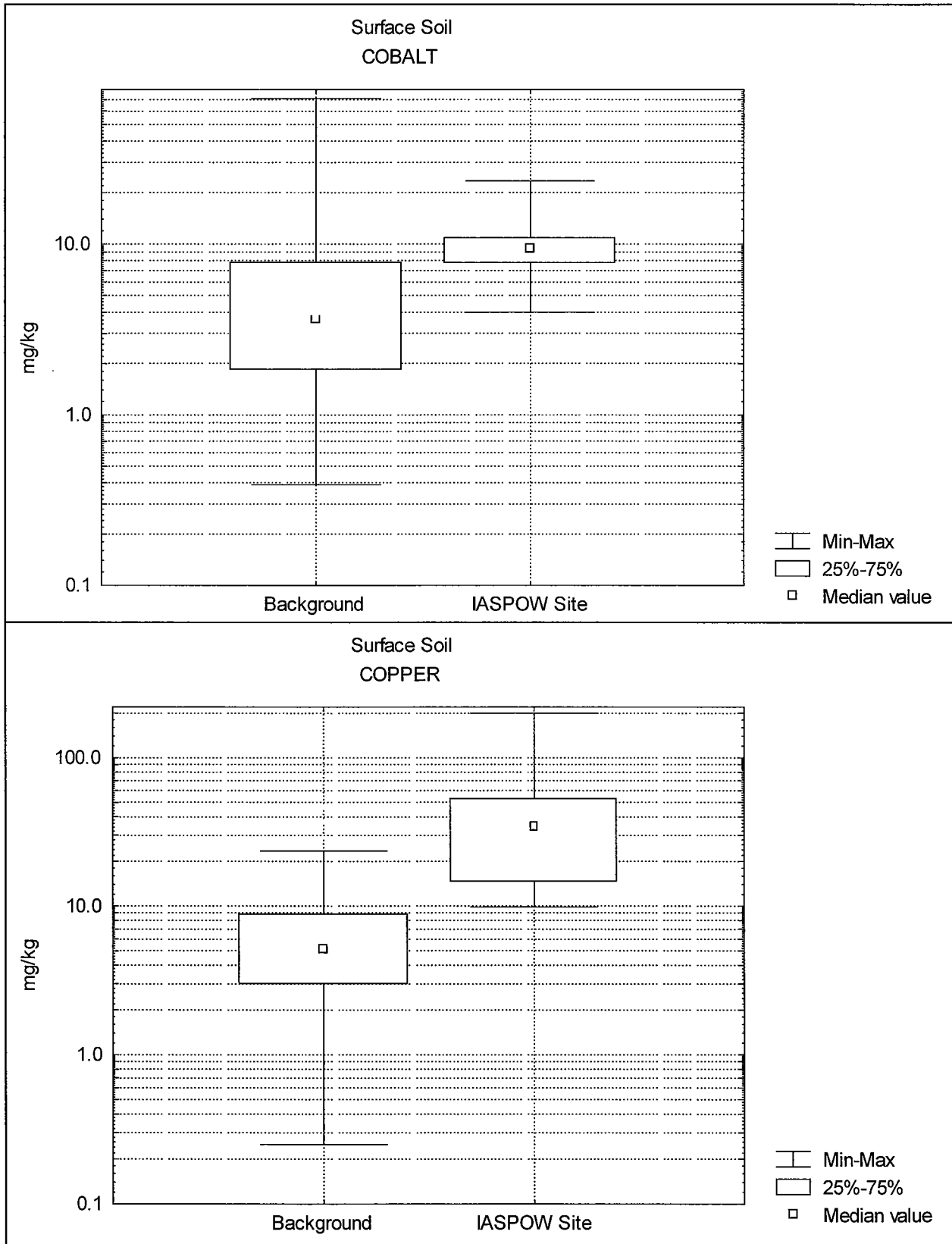


Figure 1-5

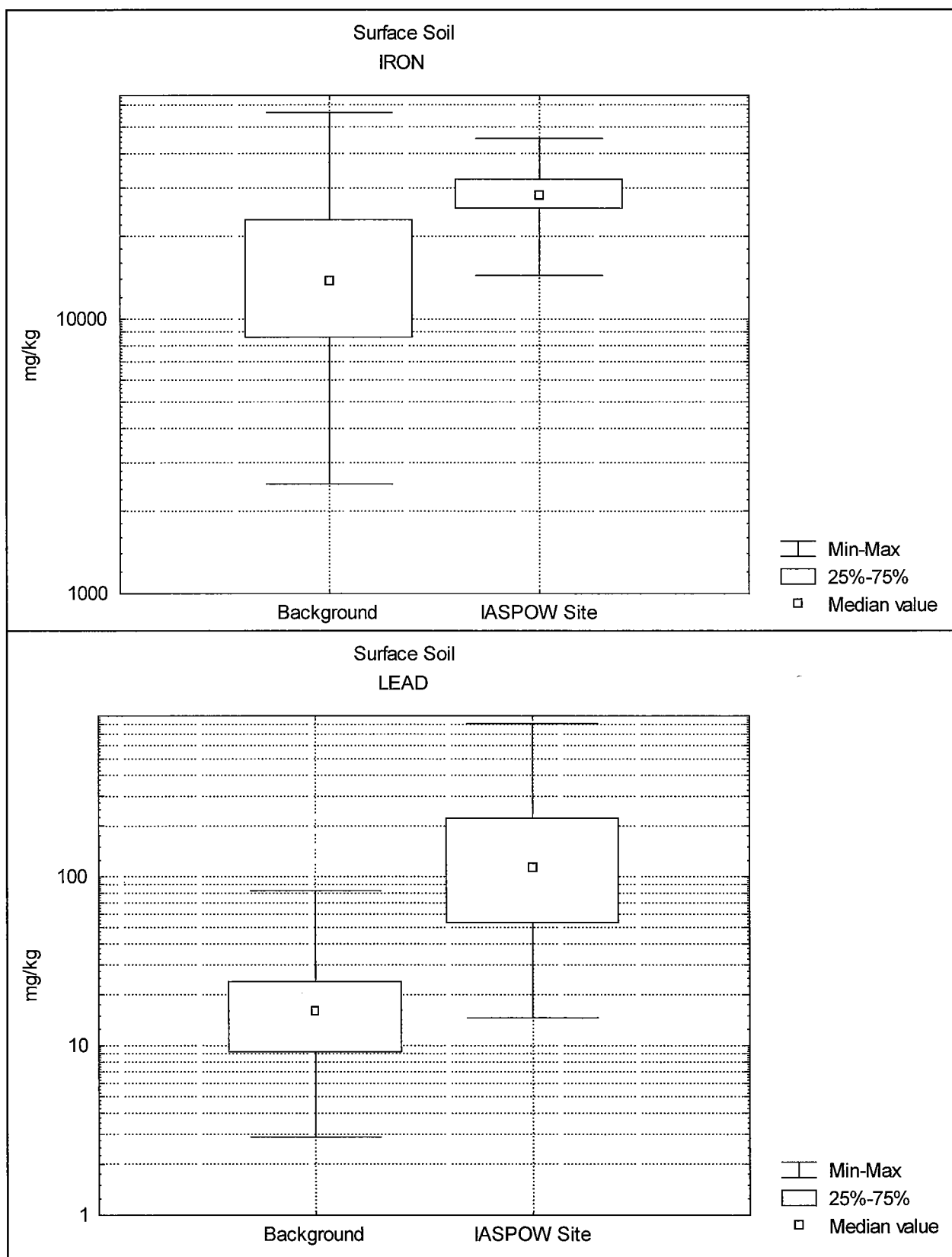


Figure 1-6

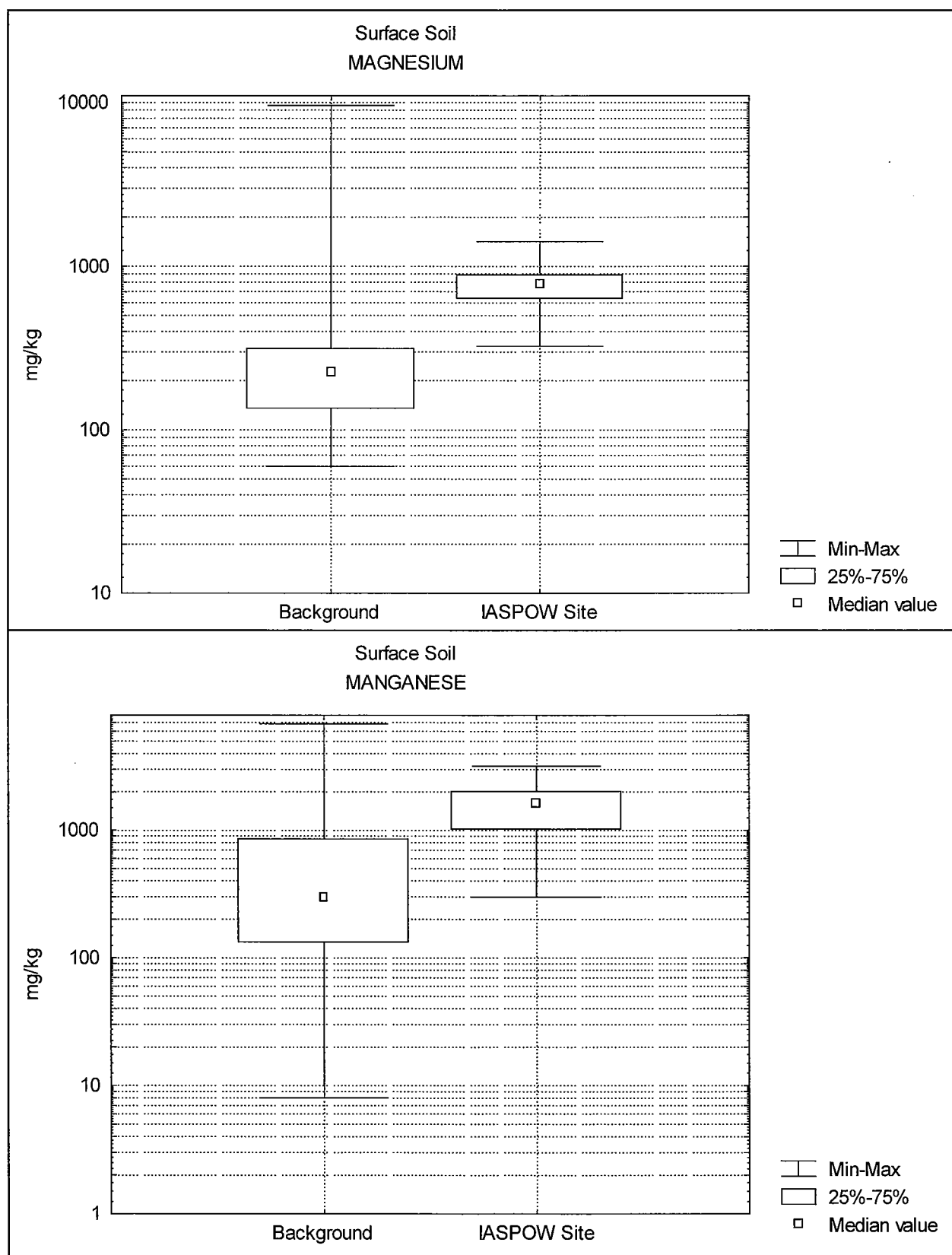


Figure 1-7

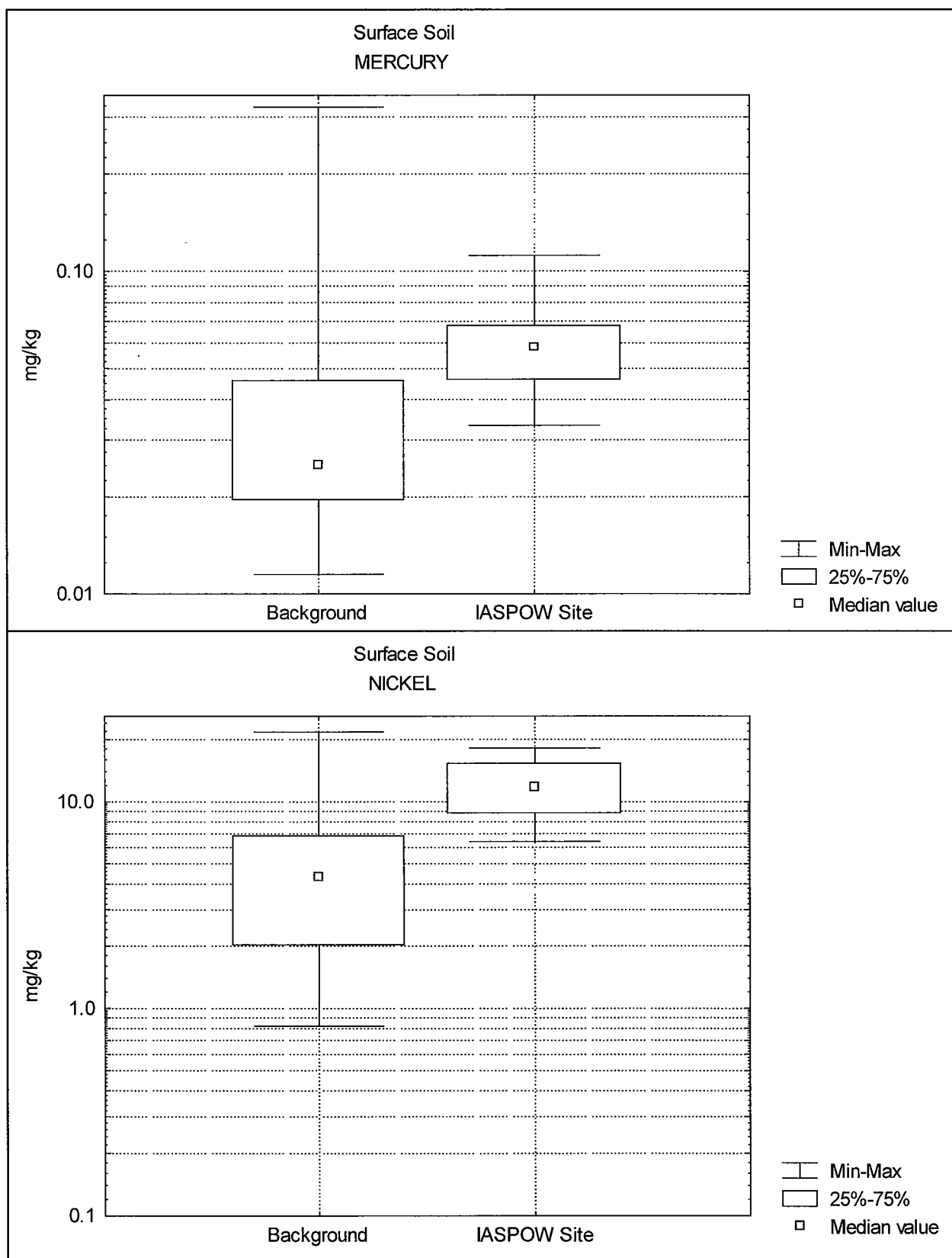


Figure 1-8

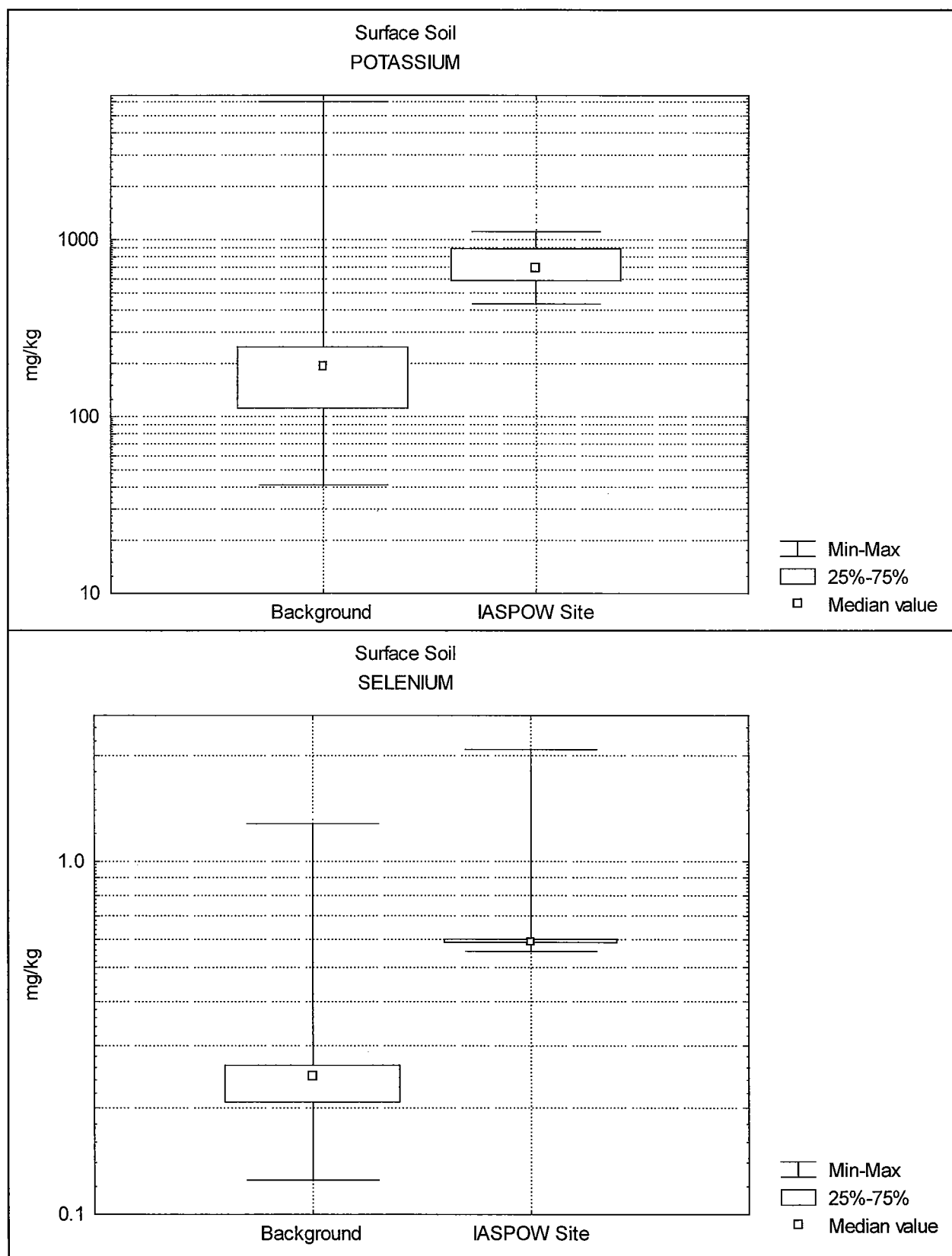


Figure 1-9

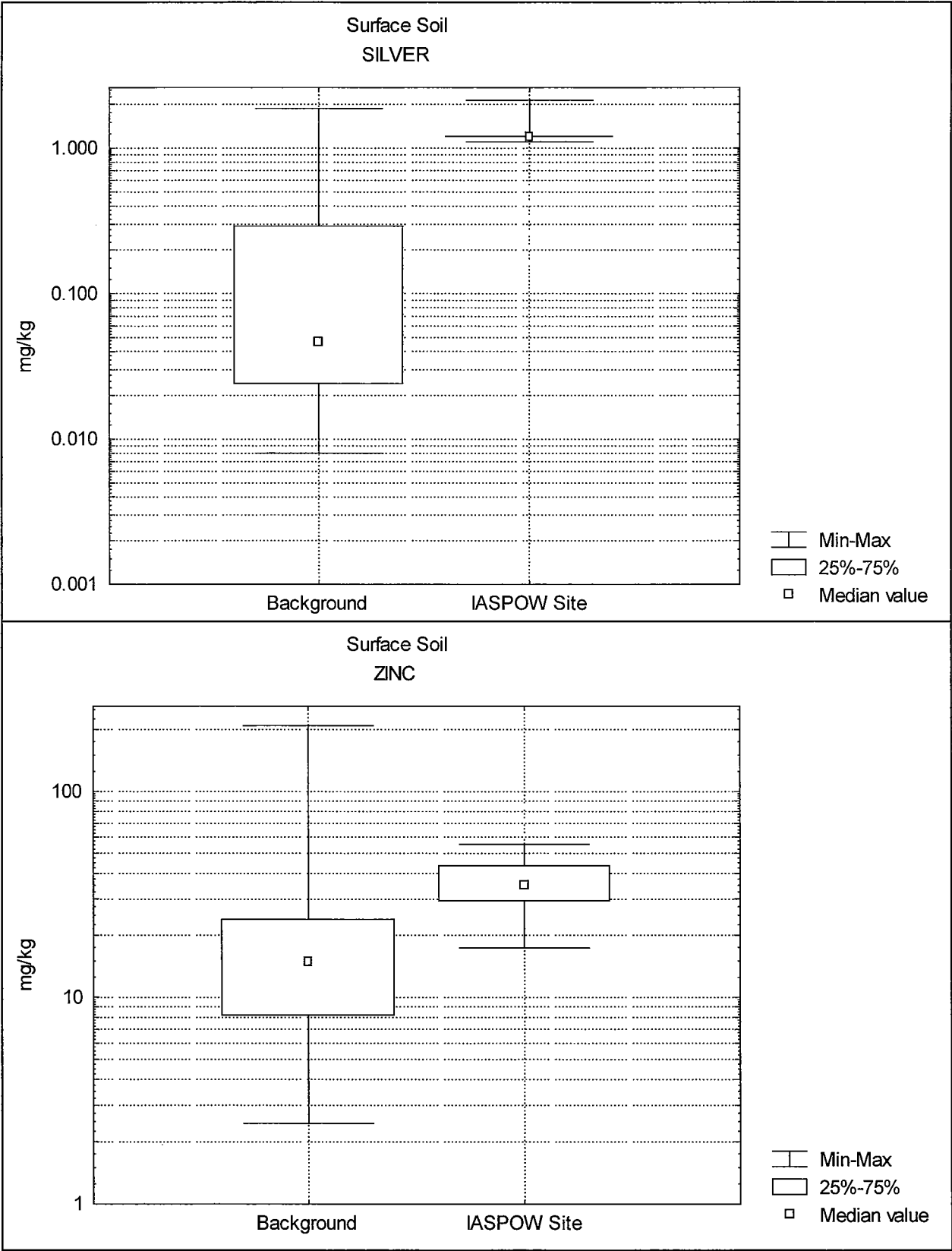


Figure 1-10

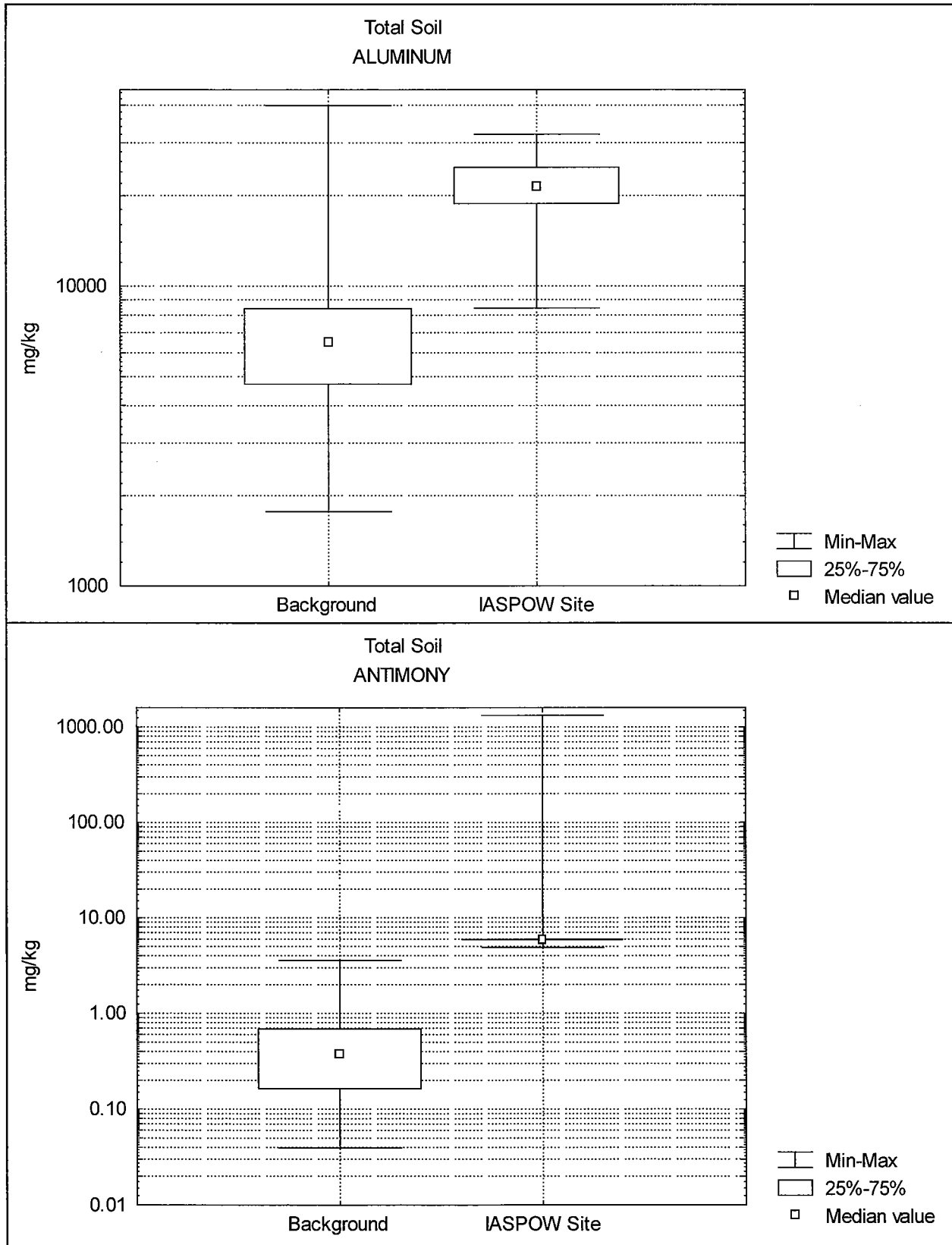




Figure 1-11

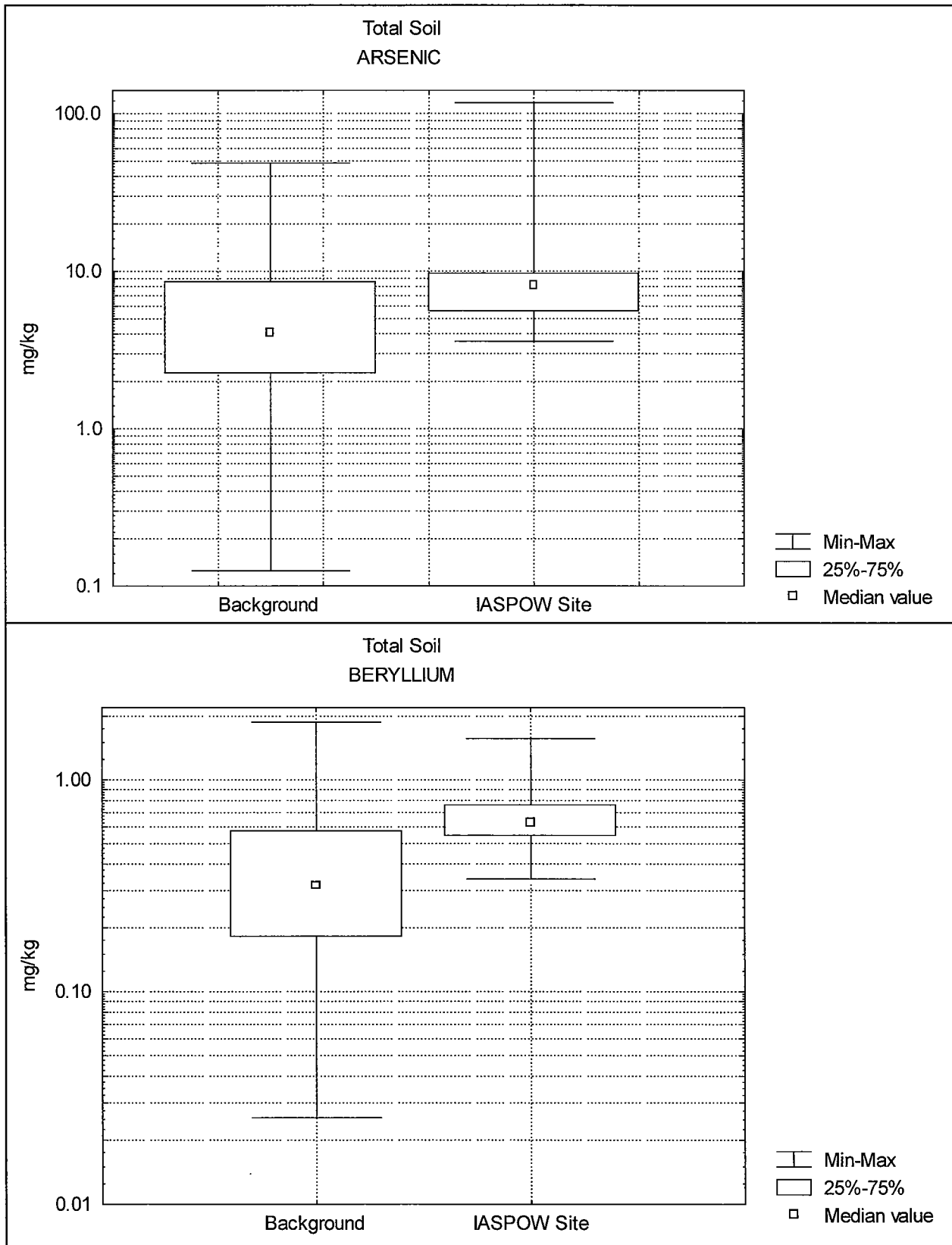


Figure 1-12

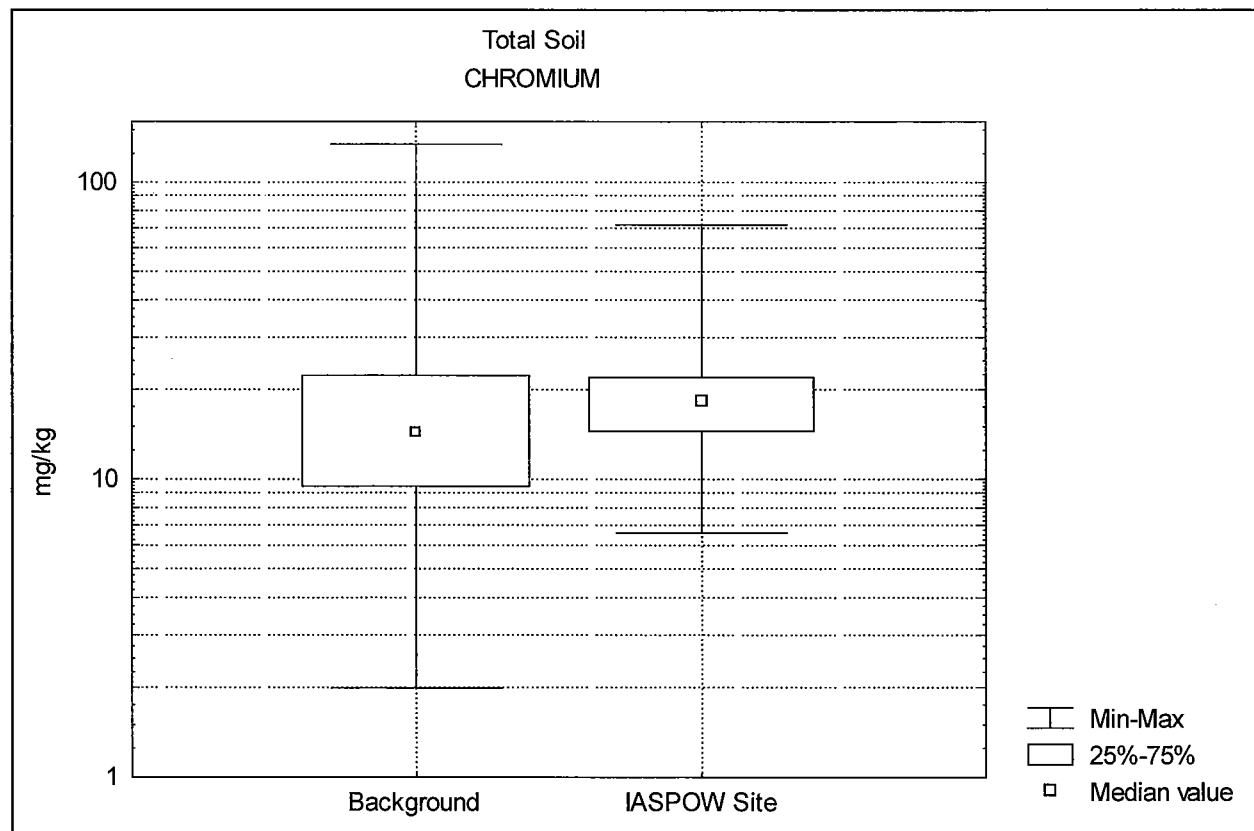
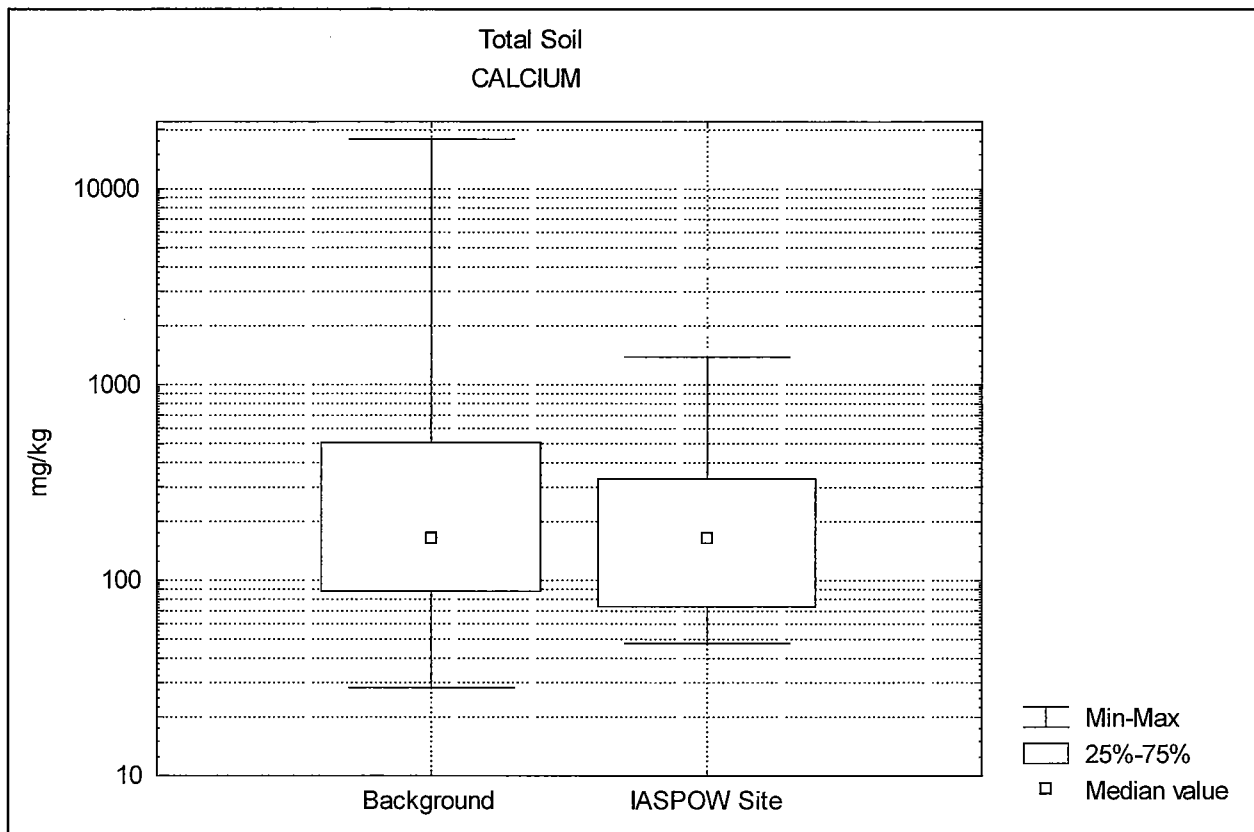


Figure 1-13

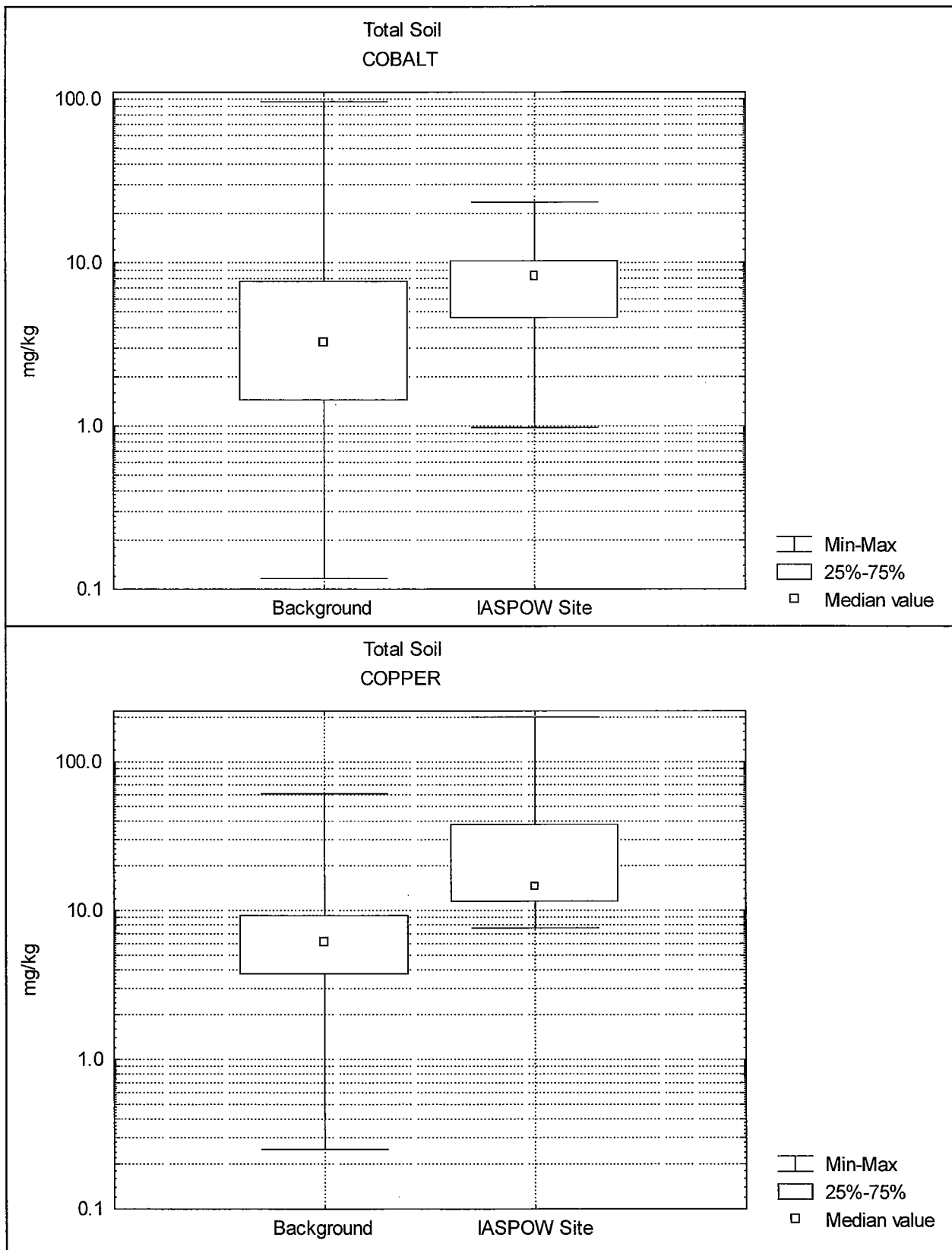


Figure 1-14

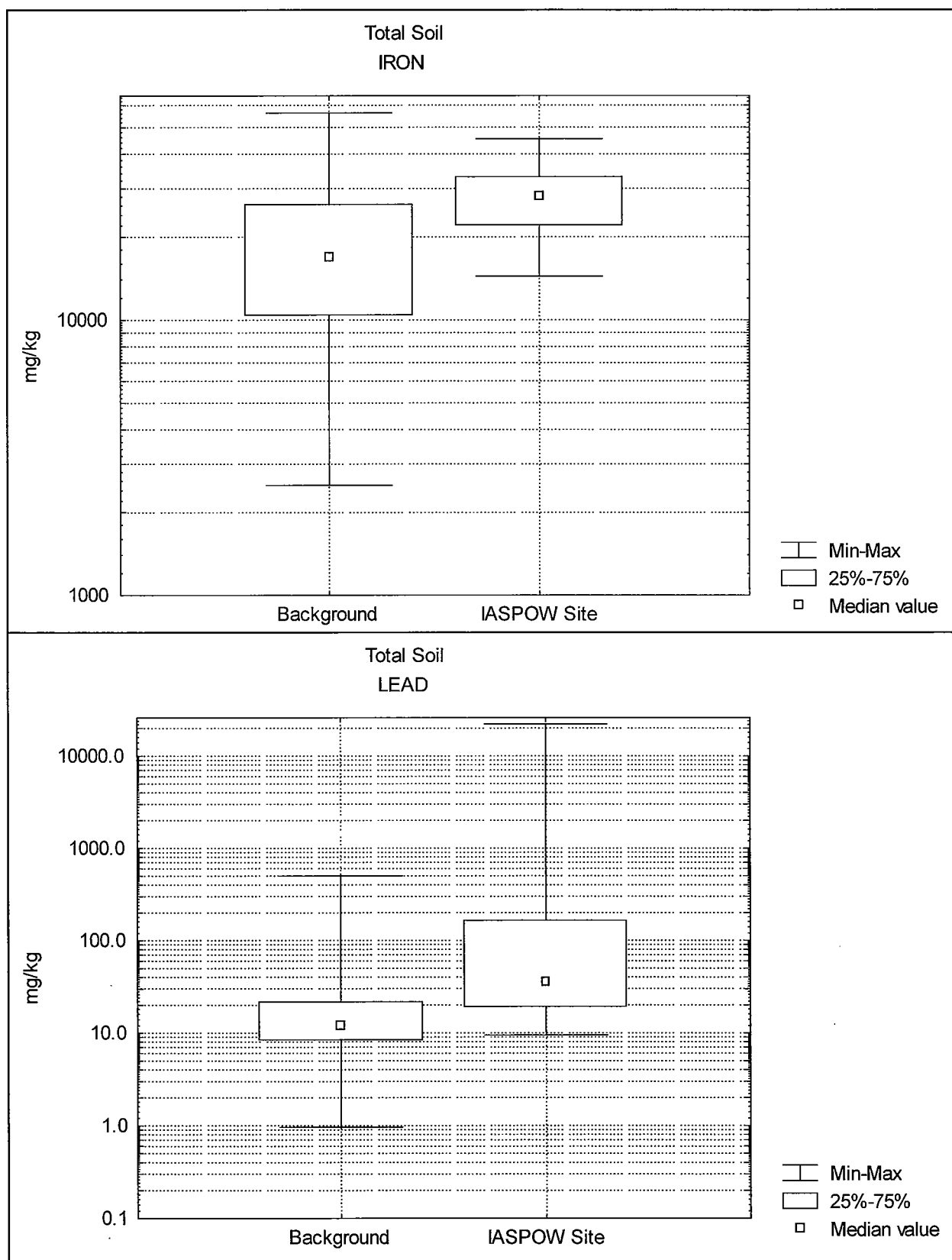


Figure 1-15

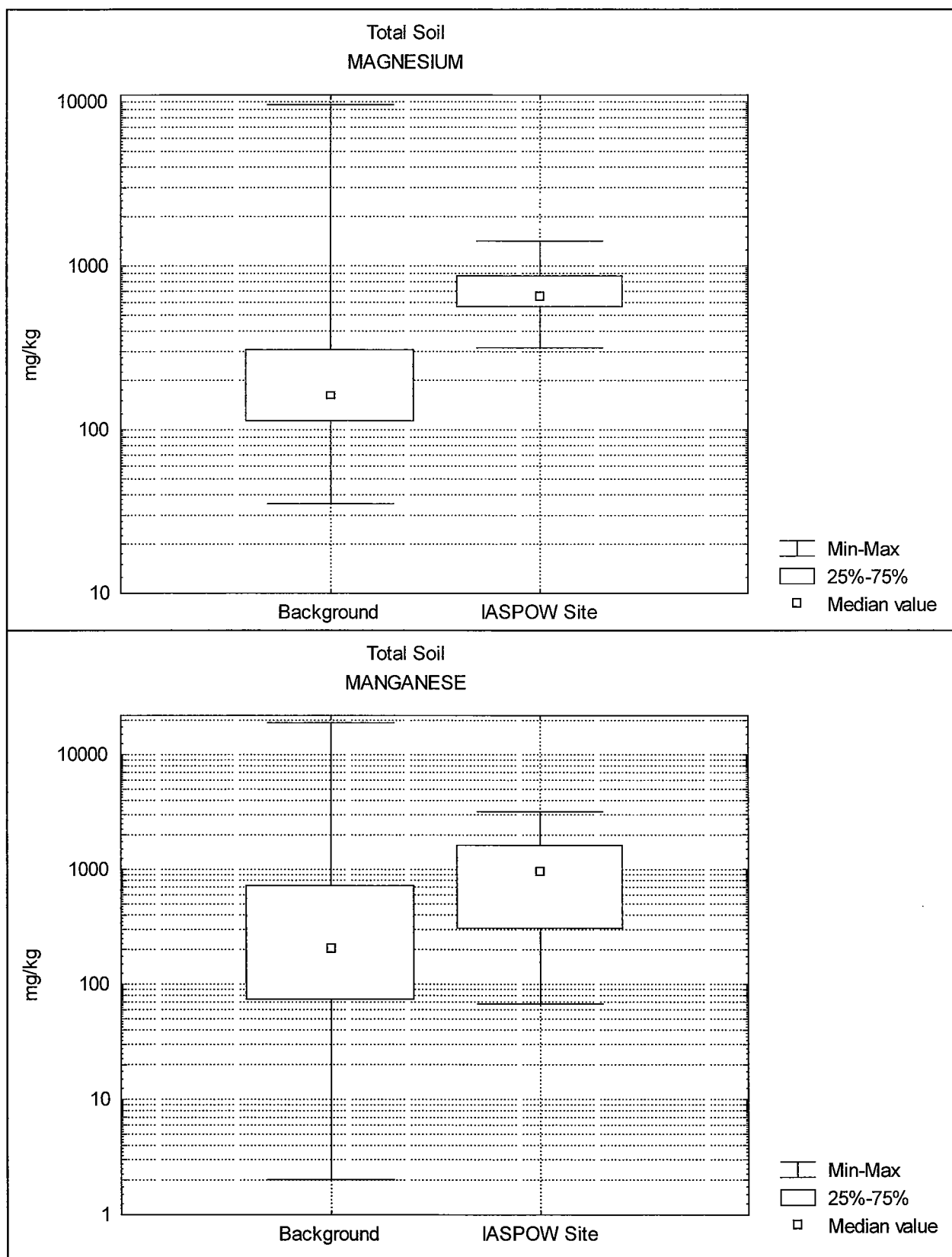


Table 1-16

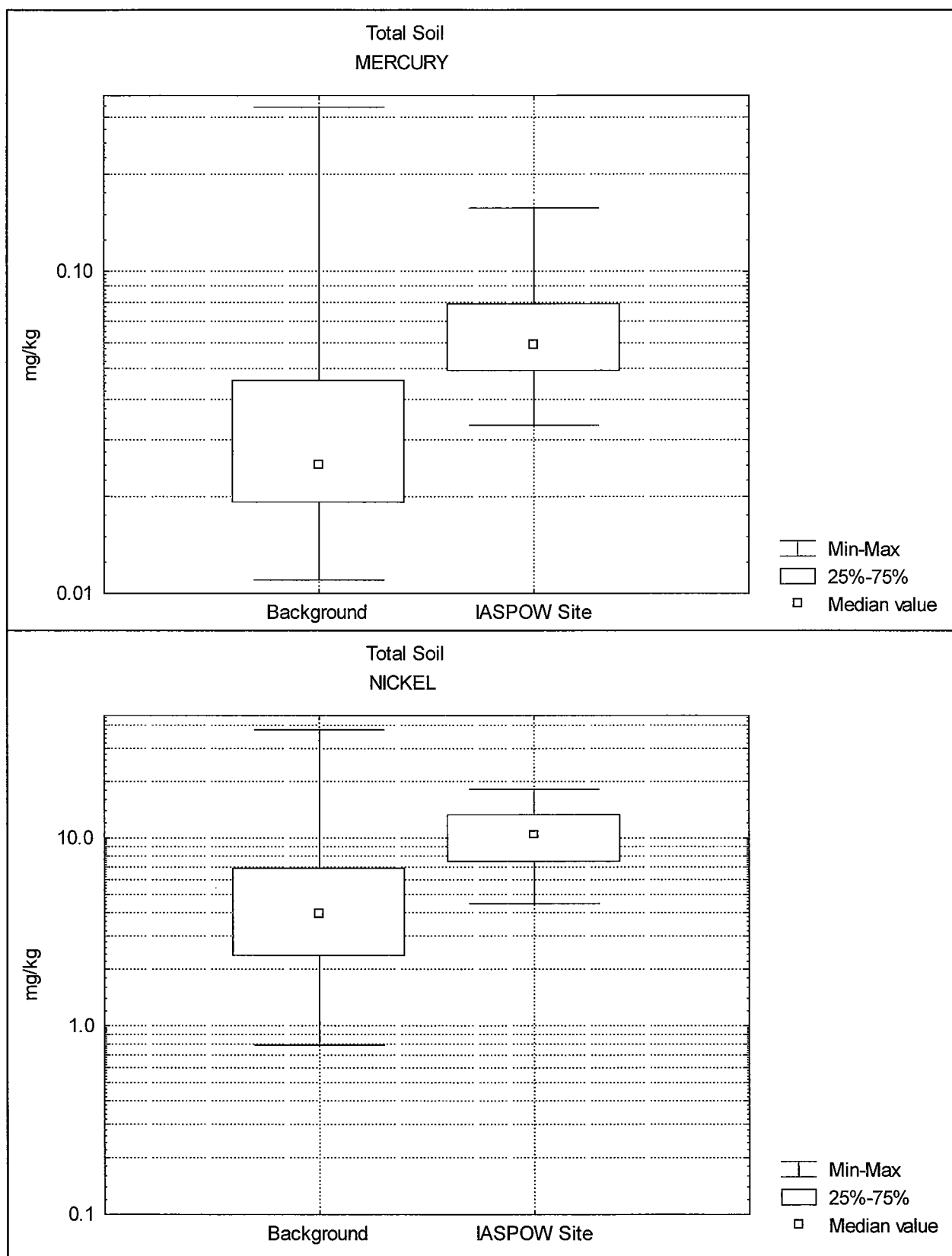


Figure 1-17

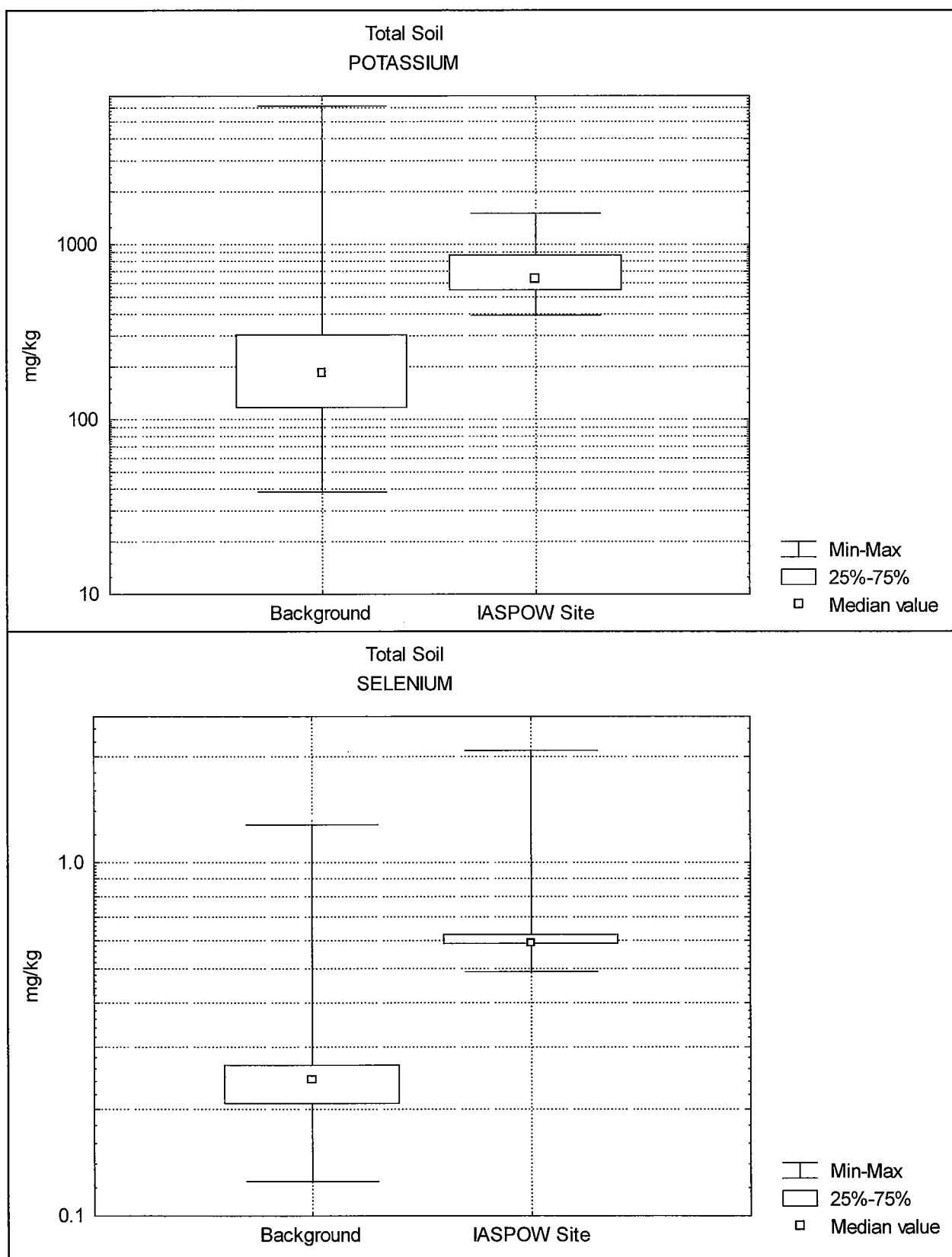


Figure 1-18

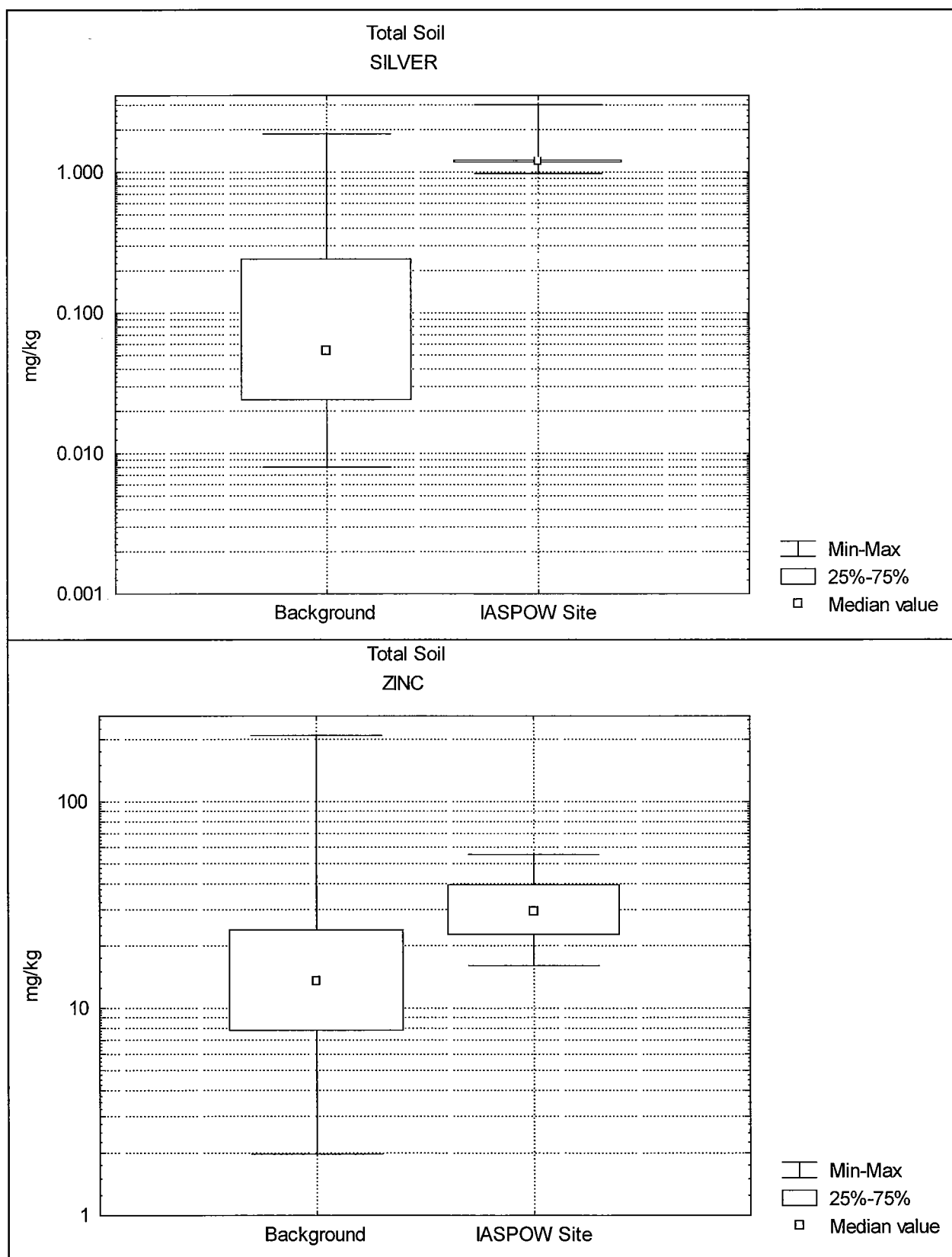
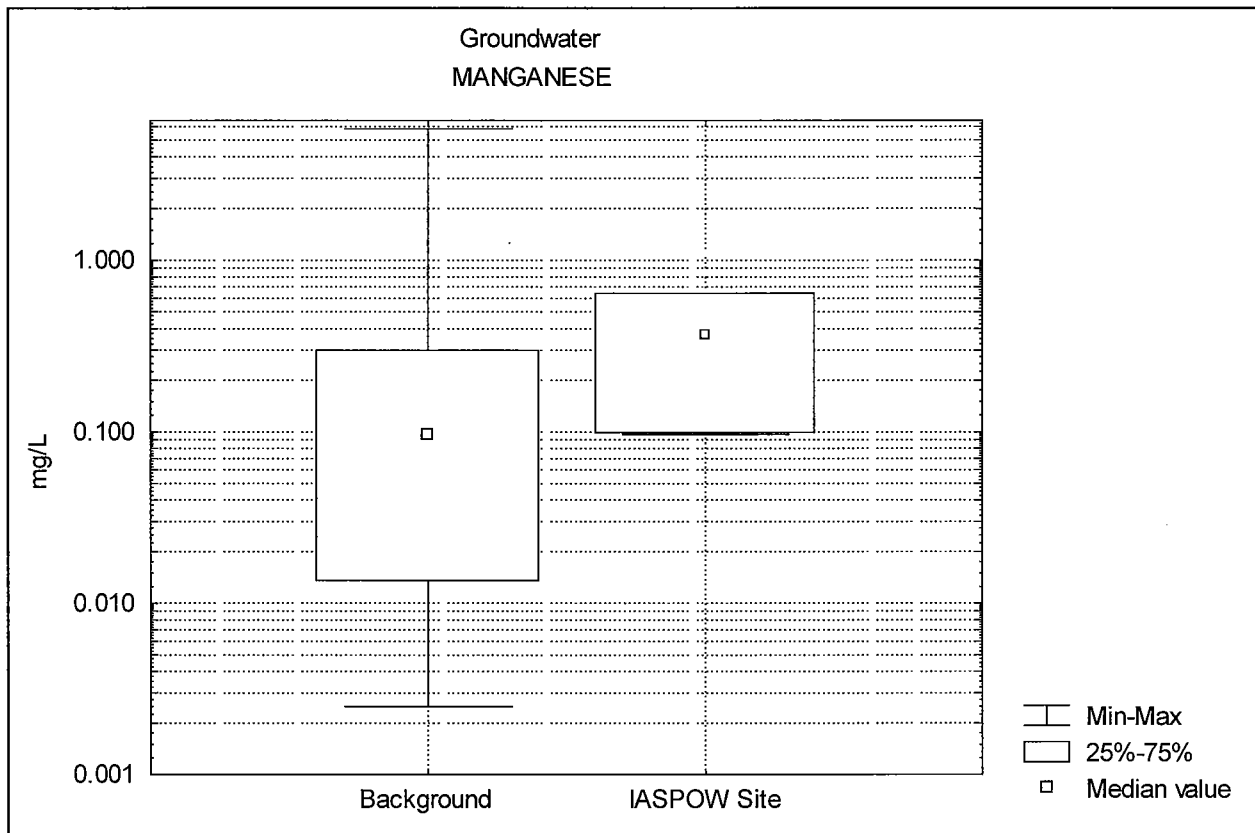




Figure 1-19



## **GEOCHEMICAL EVALUATION**

# **Geochemical Evaluation of Metals in Soil at the Impact Area South of the POW Training Facility Fort McClellan, Alabama**

## **1.0 Introduction**

This report provides the results of a geochemical evaluation of inorganic constituents in soil samples from the Impact Area South of the POW Training Facility (IASPOW), Fort McClellan, Calhoun County, Alabama. Eighteen elements in soil failed statistical comparison to background. A geochemical evaluation was performed to determine if the elevated concentrations are naturally occurring or if they contain a component of contamination.

Site samples included in the evaluations consist of 22 surface soil samples (0 to 1 foot below ground surface [bgs]), and 20 subsurface soil samples (3 to 4 feet bgs or 4 to 6 feet bgs) collected in January and October 2002. All of the site samples were analyzed for the full list of 23 target analyte list (TAL) metals. Installation-wide background data for TAL metals in soil, sediment, groundwater, and surface water are provided in the background study report (Science Applications International Corporation, 1998) and are used in the following evaluations.

## **2.0 Geochemical Evaluation Methodology**

If an analyte fails statistical comparison to background as described in the “Statistical Comparison of Site and Background Data for the Impact Area South of the POW Training Facility,” then a geochemical evaluation is performed to determine if the elevated concentrations are caused by natural processes. The importance of geochemical evaluations in distinguishing between site and background data sets has been recognized in the industry (U.S. Environmental Protection Agency, 1995; Barclift, *et al.*, 2000; U.S. Navy, 2002; Myers and Thorbjornsen, 2004). When properly evaluated, geochemistry can provide mechanistic explanations for apparently high, yet naturally occurring, constituents. Anomalous samples that may represent contamination can also be readily distinguished from uncontaminated samples. This section describes the geochemical evaluation techniques that were employed in the IASPOW site-to-background comparisons.

**Soil and Sediment.** The geochemical evaluation is based on the natural associations of trace elements with specific minerals in the soil or sediment matrix. As an example, arsenic in most

uncontaminated oxic soils is almost exclusively associated with iron oxide minerals (Bowell, 1994; Schiff and Weisberg, 1997). (The term “iron oxide” is used here to include oxides, hydroxides, oxyhydroxides, and hydrous oxides of iron.) This association of arsenic with iron oxides is a result of the adsorptive behavior of this particular trace metal in an oxic soil environment. Arsenic is present in oxic soil pore fluid as negatively charged oxyanions ( $\text{HAsO}_4^{2-}$ ,  $\text{H}_2\text{AsO}_4^-$ ) (Brookins, 1988). These anions have strong affinities to adsorb on the surfaces of iron oxides, which maintain a strong positive surface charge (Electric Power Research Institute, 1986). If a soil sample has a high percentage of iron oxides, then it is expected to have a proportionally higher concentration of arsenic.

The absolute concentrations of arsenic and iron can vary by several orders of magnitude at a site, but the arsenic/iron ratios in the samples are usually quite constant as long as no contamination is present (Daskalakis and O'Connor, 1995). If a sample has some naturally occurring arsenic plus additional arsenic from an herbicide or some other source, then it will have an anomalously high ratio relative to the other uncontaminated samples. These ratios thus serve as a powerful technique for identifying contaminated samples.

The evaluation includes the generation of plots in which detected arsenic concentrations in a set of samples are plotted on the y-axis, and the corresponding detected iron concentrations are plotted on the x-axis. The slope of a best-fit line through the samples is equal to the average arsenic-to-iron background ratio. If the samples with the highest arsenic concentrations plot on the same linear trend as the other samples, then it is most probable that the elevated concentrations are natural, and are caused by the preferential enrichment of iron oxides in those samples. If the site samples with elevated arsenic concentrations plot above the trend displayed by the uncontaminated samples, then there is evidence that those samples have an excess contribution of arsenic, and contamination may be indicated.

Each trace element is associated with one or more minerals in the soil matrix. Vanadium and selenium, along with arsenic, form anionic species in solution and are associated with iron oxides, which maintain a positive surface charge. Divalent metals such as barium, cadmium, lead, and zinc tend to form cationic species in solution and are attracted to clay mineral surfaces, which maintain a negative surface charge. These trace elements would be evaluated against aluminum, which is a major component of clay minerals. Manganese oxides also have an affinity to adsorb divalent cations such as barium, cobalt, and lead (Kabata-Pendias, 2001). These trace elements would be evaluated against manganese.

### **3.0 Results of the Geochemical Evaluation for Multiple Elements in Soil**

This section presents the results of the geochemical evaluation of aluminum, antimony, arsenic, barium, beryllium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, and zinc in soil samples from the IASPOW. Correlation plots are provided in Attachment 1, and a list of samples containing anomalously high element concentrations is provided in Table 1.

#### **Aluminum**

The IASPOW soil boring logs note the presence of clays in most of the sampled intervals. Aluminum is a primary component of common soil-forming minerals such as clays, feldspars, and micas. Iron oxides are minerals that are also common in soil. Clays and iron oxides tend to exist as very fine particles, so both aluminum and iron are enriched in samples with finer grain sizes. A plot of aluminum versus iron concentrations can be used to qualitatively assess the relative abundance of these minerals in site soil (Figure 1). Site surface soil samples are represented by open triangles, site subsurface soil samples by filled triangles, and background soil samples by filled circles. The site samples exhibit higher aluminum concentrations than many of the background samples, but they also contain proportionally higher iron and lie on the general background trend. This indicates that aluminum in the site samples is naturally occurring. It is worth noting that iron oxide and clay minerals adsorb specific trace elements (as discussed in Section 2.0), so samples that plot on the upper end of the trend in Figure 1 are expected to contain proportionally higher concentrations of trace elements.

#### Conclusion

Aluminum detected in the site soil samples is naturally occurring.

#### **Antimony**

Antimony has an affinity to adsorb on clays (Kabata-Pendias, 2001), so a positive correlation between antimony and aluminum is expected for uncontaminated samples. The background samples form a linear trend with a positive slope in a plot of antimony versus aluminum (Figure 2). Two of the site samples with detectable antimony have slightly higher antimony concentrations (5.39 J and 5.41 J mg/kg) than the background samples, but they also contain proportionally higher aluminum and lie on the linear trend established by the background samples. Antimony in these samples is associated with clays at a ratio consistent with those of the background samples, and is natural. Subsurface soil sample QG0006 (obtained from 3 to 4 feet bgs at sample location IMP-IASPOW-GP03), however, contains the highest antimony concentration of both data sets (1,330 mg/kg) but only moderate aluminum, and lies well above the background trend. Elevated antimony in this sample is unexpected, and should be considered suspect.

#### Conclusion

The antimony concentration detected in sample QG0006 is anomalously high and may contain a component of contamination. Antimony concentrations detected in the other site soil samples are naturally occurring.

**Table 1**

**Samples With Anomalous Element Concentrations  
Impact Area South of the POW Training Facility  
Fort McClellan, Alabama**

<b>Medium</b>	<b>Sample Location</b>	<b>Sample Number</b>	<b>Element(s)</b>
Surface Soil	IMP-IASPOW-GP04	QG0007	Lead
Surface Soil	IMP-IASPOW-GP09	QG0016	Lead
Surface Soil	IMP-IASPOW-GP10	QG0022	Copper, Lead
Surface Soil	IMP-IASPOW-GP11	QG0024	Lead
Surface Soil	IMP-IASPOW-GP12	QG0026	Copper, Lead
Surface Soil	IMP-IASPOW-GP13	QG0028	Copper, Lead
Surface Soil	IMP-IASPOW-GP15	QG0033	Copper, Lead
Surface Soil	IMP-IASPOW-GP20	QG0043	Lead
Subsurface Soil	IMP-IASPOW-GP02	QG0004	Copper, Lead
Subsurface Soil	IMP-IASPOW-GP03	QG0006	Antimony, Arsenic, Lead

## **Arsenic**

As discussed in Section 2.0, arsenic has a strong affinity to adsorb on the surfaces of iron oxides in soil, so a positive correlation is expected between arsenic and iron in uncontaminated samples. A plot of arsenic versus iron reveals a common linear trend for the background samples and most of the site samples (Figure 3). Most of the site samples with elevated arsenic also exhibit proportionally higher iron, and lie on the linear trend. Arsenic in these samples is associated with iron oxides at a relatively constant ratio, and is natural. The exception is subsurface soil sample QG0006 (collected from 3 to 4 feet bgs at sample location IMP-IASPOW-GP03), which contains the highest arsenic concentration of both data sets (117 mg/kg), but only moderate iron. Elevated arsenic in this sample should be considered suspect.

### Conclusion

The arsenic concentration in sample QG0006 is anomalously high and may contain a component of contamination. Anomalous concentrations of antimony and lead have also been identified in this sample (Table 1). Arsenic concentrations detected in the other site soil samples are naturally occurring.

## **Barium**

Manganese oxides have an affinity to adsorb divalent cations such as barium and cobalt (Kabata-Pendias, 2001). If a soil sample contains a high proportion of manganese oxides, then it is expected to contain high concentrations of manganese and associated trace elements. The site and background samples form a strong collinear trend in a plot of barium versus manganese (Figure 4). The site samples with high barium concentrations also contain high manganese, and lie on the trend established by the other samples. This indicates that barium in these samples is associated with manganese oxides at a relatively constant ratio, and is natural.

### Conclusion

Barium concentrations detected in the site soil samples are naturally occurring.

## **Beryllium**

A plot of beryllium versus manganese is provided in Figure 5. The site and background samples form a common linear trend with a positive slope. The site samples that have the highest beryllium concentrations also have the highest manganese, and lie on the trend established by the other samples. Beryllium in the site samples is associated with manganese oxides at a relatively constant ratio, and is natural.

### Conclusion

Beryllium detected in the site soil samples is naturally occurring.

## **Chromium**

Chromium has an affinity to adsorb on iron oxides (Cornell and Schwertmann, 1996), so a positive correlation between chromium and iron is expected for uncontaminated samples. A plot of chromium versus iron reveals a collinear trend for the site and background samples (Figure 6). The site samples with high chromium concentrations contain proportionally higher iron and lie

on the background trend. This indicates that chromium in these samples is associated with iron oxides at a relatively constant ratio, and is natural.

#### Conclusion

Chromium concentrations detected in the site soil samples are naturally occurring.

#### **Cobalt**

Manganese oxides have an affinity to adsorb divalent cations such as barium and cobalt (Kabata-Pendias, 2001). If a soil sample contains a high proportion of manganese oxides, then it is expected to contain high concentrations of manganese and associated trace elements. A plot of cobalt versus manganese reveals a common linear trend with a positive slope for the site and background samples (Figure 7). The site samples with high cobalt also contain high manganese, and lie on the trend established by the other samples. These observations suggest that cobalt in the soil samples is associated with manganese oxides at a relatively constant ratio, and is natural.

#### Conclusion

Cobalt detected in the site soil samples is naturally occurring.

#### **Copper**

Copper in soil has an affinity to adsorb on the surfaces of minerals such as clays and iron oxide minerals (Kabata-Pendias, 2001). The background samples and most of the site samples form a linear trend in a plot of copper versus iron (Figure 8). Most of the site samples with high copper concentrations also exhibit proportionally higher iron and lie on the background trend. Copper in these samples has a natural source. The exceptions are the four surface soil samples and single subsurface soil sample with copper concentrations of 61.1 mg/kg and higher. These samples exhibit high copper concentrations but only moderate iron, and lie above the trend formed by the other samples. Elevated copper in these samples should be considered suspect. Table 1 lists the samples that contain anomalously high copper.

#### Conclusion

Copper concentrations in four surface soil samples and one subsurface soil sample are anomalously high and may contain a component of contamination (Table 1).

#### **Iron**

As discussed in the Aluminum evaluation, iron oxides and clays are common soil-forming minerals and tend to concentrate specific trace elements. The plot of aluminum versus iron concentrations provides a qualitative indicator of the relative abundance of these minerals in site soil (Figure 1). The site samples exhibit higher iron concentrations than many of the background samples, but they also contain proportionally higher aluminum and lie on the general background trend. Iron in the site samples is naturally occurring. It is important to note that iron oxides and clays adsorb specific trace elements (as discussed in Section 2.0), so samples that plot on the upper end of the trend in Figure 1 are expected to contain proportionally higher concentrations of trace elements.

#### Conclusion

Iron detected in the site soil samples is naturally occurring.



## **Lead**

Manganese oxides in soil have a strong affinity to adsorb divalent cations such as barium and lead (Kabata-Pendias, 2001). Uncontaminated samples that contain a high percentage of manganese oxides will contain elevated manganese concentrations and proportionally higher lead. A common linear trend with a positive slope is observed for the background samples and most of the site samples in a plot of lead versus manganese (Figure 9). Many of the site samples with high lead also have high manganese, and lie on the linear trend. This indicates that the lead in these samples is associated with manganese oxides at ratios consistent with those of the background samples, and is natural. The exceptions are the eight surface soil samples and two subsurface soil samples with lead concentrations of 188 mg/kg and higher. These samples exhibit high lead concentrations but only moderate manganese, and lie above the trend formed by the other samples. These samples most likely contain a component of contamination (Table 1).

### Conclusion

Lead concentrations detected in eight surface soil samples and two subsurface soil samples are anomalously high and may contain a component of contamination (Table 1).

## **Magnesium**

Magnesium is a common component of minerals such as clays and micas, which contain aluminum as a primary constituent. A plot of magnesium versus aluminum reveals a generally linear trend for the background samples (Figure 10). The site samples are highly linear and lie on the background trend. Magnesium in the site samples is associated with aluminum-bearing minerals at a relatively constant ratio, and is natural.

### Conclusion

Magnesium in the site soil samples is naturally occurring.

## **Manganese**

As discussed previously, manganese oxides are common in soil and have an affinity to adsorb specific trace elements such as barium. A positive correlation is thus expected between manganese and associated trace elements in uncontaminated soil samples. The positive correlation between barium and manganese, and the absence of outliers plotting off the linear trend on the correlation plot, indicate a natural source for these two elements (Figure 4).

### Conclusion

Manganese in the site soil samples is naturally occurring.

## **Mercury**

Mercury concentrations in soil are commonly controlled through organic complex formation (Kabata-Pendias, 2001), so poor correlations between mercury and iron or mercury and aluminum are often observed, even in uncontaminated soil samples. A plot of mercury versus iron is provided in Figure 11. All of the site samples lie on the general background trend, indicating that the mercury in these samples is associated with iron oxides at ratios consistent with those of the background samples, and is natural.

### Conclusion

Mercury detected in the site soil samples is naturally occurring.

### **Nickel**

Nickel is commonly associated with clays in soils (Kabata-Pendias, 2001). A plot of nickel versus aluminum reveals a linear trend with a positive slope for most of the background samples, and all of the site samples lie on this trend (Figure 12). The site samples with high nickel concentrations are also characterized by high aluminum content, and lie on the linear trend. Nickel in the site samples is associated with clays at a relatively constant ratio, and is natural.

### Conclusion

Nickel detected in the site soil samples is naturally occurring.

### **Potassium**

Potassium is a major element that is a common constituent of minerals such as clays, which also contain aluminum. The background samples form a generally linear trend in a plot of potassium versus aluminum (Figure 13). The site samples have higher potassium than many of the background samples, but they have proportionally higher aluminum and lie on the linear trend. The observations indicate that the site samples are preferentially enriched in clays (and other aluminum-bearing minerals) relative to background, and that the potassium is natural.

### Conclusion

Potassium detected in the site soil samples is naturally occurring.

### **Selenium**

As explained in Section 2.0, selenium has a strong affinity to adsorb on iron oxides in oxic soils, so a positive correlation between selenium and iron is expected for uncontaminated soil samples. Comparison to background is hindered because of the high percentage of nondetects in the background data set. However, a plot of selenium versus iron reveals a generally linear trend with a positive slope for the site samples, and the two background samples with detectable selenium lie on this trend (Figure 14). The site samples with high selenium generally have proportionally higher iron, and lie on the linear trend. These observations indicate that selenium in the samples is associated with iron oxides at a relatively constant ratio, and is natural.

### Conclusion

Selenium detected in the site soil samples is naturally occurring.

### **Silver**

A plot of silver versus iron is provided in Figure 15. The site samples with detectable silver have higher concentrations than most of the background samples, but they also have high iron concentrations and form a linear trend with a positive slope ( $R^2 = 0.99$  for the surface soil interval). It is likely that these site samples are preferentially enriched in iron oxides and associated trace elements, and that the silver is natural. It is important to note that all but one of the site detections are estimated ("J"-qualified) values below the reporting limit, and that such values are highly uncertain. In comparison, the background detections are mostly unestimated

concentrations ranging from 0.019 to 1.87 mg/kg, with a mean of 0.128 mg/kg (14 of the 82 background samples are estimated values). Additionally, the site samples are characterized by higher reporting limits relative to the background samples: the site reporting limits range from 1.96 to 2.48 mg/kg, with a mean of 2.36 mg/kg, whereas the reporting limits for the background nondetects range from 0.016 to 1.2 mg/kg, with a mean of 0.293 mg/kg [reporting limit data are unavailable for the background detected concentrations]. The uncertainty associated with the estimated site concentrations, combined with the order-of-magnitude difference in reporting limits between the data sets, likely explains why the site samples do not exhibit the same Ag/Fe ratios exhibited by the background samples.

#### Conclusion

Silver concentrations detected in the site soil samples are most likely natural.

#### **Zinc**

Zinc often substitutes for magnesium in silicate minerals (Kabata-Pendias, 2001). A plot of zinc versus magnesium is provided in Figure 16. All of the site soil samples lie on the linear background trend, and the samples with high zinc also contain proportionally higher magnesium. These observations indicate that zinc in the soil samples has a natural source.

#### Conclusion

Zinc concentrations detected in the site soil samples are naturally occurring.

### **4.0 Summary**

Geochemical evaluation indicates that detected concentrations of aluminum, barium, beryllium, chromium, cobalt, iron, magnesium, manganese, mercury, nickel, potassium, selenium, silver, and zinc concentrations in the IASPOW surface and subsurface soil samples are naturally occurring. Antimony and arsenic concentrations detected in the surface soil samples are naturally occurring, but subsurface soil sample QG0006 contains anomalously high concentrations of antimony and arsenic that may contain a component of contamination. Copper and lead have anomalously high concentrations in both the surface and subsurface soil intervals, and these concentrations should be considered suspect. A list of the samples that contain anomalous element concentrations is provided in Table 1.

### **5.0 References**

Barclift, D., J. Heath, and A. Drucker, 2000, "Focus on Environmental Background Data Analysis," *Soil Sediment & Groundwater*, August/September, pp. 10-17.

Bowell, R. J., 1994, "Sorption of Arsenic by Iron Oxides and Oxyhydroxides in Soils," *Applied Geochemistry*, Vol. 9, pp. 279-286.

Brookins, D. G., 1988, *Eh-pH Diagrams for Geochemistry*, Springer-Verlag.

Cornell, R. M. and U. Schwertmann, 1996, *The Iron Oxides: Structure, Properties, Reactions, Occurrence, and Uses*, VCH, Weinheim.

Daskalakis, K. D. and T. P. O'Connor, 1995, "Normalization and Elemental Sediment Contamination in the Coastal United States," *Environmental Science & Technology*, Vol. 29, No. 2, pp. 470-477.

Electric Power Research Institute, 1986, *Speciation of Selenium and Arsenic in Natural Waters and Sediments, Volume 2: Arsenic Speciation*, EPRI EA-4641, Palo Alto, California.

Kabata-Pendias, A., 2001, *Trace Elements in Soils and Plants*, Third Edition, CRC Press.

Myers, J. and K. Thorbjornsen, 2004, "Identifying Metals Contamination in Soil: A Geochemical Approach," *Soil & Sediment Contamination: an International Journal*, Vol. 13, No. 1 (in press).

Science Applications International Corporation, 1998, *Final Background Metals Survey Report, Fort McClellan, Anniston, Alabama*, July.

Schiff, K. and S. B. Weisberg, 1997, "Iron as a Reference Element for Determining Trace Metal Enrichment in California Coastal Shelf Sediments," in: S. Weisberg, C. Francisco, and D. Hallock, (eds.), *Southern California Coastal Water Research Project Annual Report 1995-96*, pp. 68-78.

U.S. Environmental Protection Agency, 1995, *Determination of Background Concentrations of Inorganics in Soils and Sediments at Hazardous Waste Sites*, Office of Research and Development, EPA/540/S-96/500, December.

U.S. Navy, 2002, *Guidance for Environmental Background Analysis, Volume 1: Soil*, NFESC User's Guide UG-2049-ENV, Naval Facilities Engineering Command, Washington, D.C., April.

## **ATTACHMENT 1**

